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EXPLOSIVE ANCHOR FOR SALVAGE OPERATIONS - PROGRESS AND STATUS

By

J. E. Smith

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NAVAL CIVIL ENGINEERING LABORATORY
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INTRODUCTION

The U. S. Navy has an urgent requirement for improved and expanded anchoring proficiency for conducting salvage operations. A serious disadvantage with conventional anchors such as the EELLS, now used as the U. S. Navy Standard salvage anchor, is that in hard seafloors they hold only if they wedge in a crevice or snag on an outcropping. Also, large amounts of beach gear are associated with their use and much time often is required to pull and set them. Changes in direction of pull and uplift loads reduce their capacities.

The U. S. Navy Supervisor of Salvage is sponsoring a program being conducted by the U. S. Naval Civil Engineering Laboratory to develop a new anchor that will alleviate the problems with conventional anchors in salvage work. A propellant actuated anchor, commonly termed "explosive anchor", was designed, fabricated, and tested. It successfully embedded into coral seafloors and attained holding capacities in excess of the working strength of a standard Navy beach gear leg. Also, it demonstrated a potential for service in sand and mud seafloors. However, improvements in the design are necessary to gain the broader range of capabilities necessary to meet acceptable operational standards.

BACKGROUND

The critical problem of establishing dependable, firm anchors in coral is the primary basis for the new anchor development program. However, it is desired to incorporate as broad a range of salvage anchoring capabilities into the new anchor as practicable.

Salvage vessels are employed most of the time on missions other than salvage. Consequently, the special gear and equipment needed for salvage attempts is employed infrequently, requires much stowage space and is expensive to maintain and transport.

Quick response to a stranding results in better prospects of success and in limiting damage to the stranded ship and its cargo. Once on the scene, fast deployment of anchors and associated gear such as the beach gear legs is vital. Once the anchors are in place, it is of extreme importance that they hold firmly without displacing.

Conventional anchors require long scopes of line and much chain because the pulling force must be near parallel to the seafloor. Consequently, extra equipment must be carried to effectively place, embed, and utilize the anchors.

Since conventional anchors are expected to drag somewhat during the setting process, much effort and time often are expended in dragging them excessive distances anticipating that ultimately they will develop

their full rated holding capacity. Instead, the anchors may hold only enough to keep alive hopes of attaining greater capacities. Or, after being dragged a limited distance, sufficient holding may develop to justify, in the salvor's judgment, completing the full rigging arrangement. When the pull-off loads are then applied, the anchors begin to drag, and continue to displace with an undulating holding capacity, the peak holding always being less than what is needed. Further compounding the dragging problem is that new purchases must be made on the beach gear leg as the anchor moves, a time-consuming and exhausting endeavor.

It is evident that other advantages than the ability to anchor in hard seafloor portend from explosive anchors. Chief qualities that could prove advantageous are the ability to embed directly into the seafloor and the ability to resist loads from any direction immediately without preset dragging. Less amounts of chain and wire rope would be required.

OPERATIONAL CRITERIA

The objective of the program is to obtain a new anchor design that will overcome the anchoring deficiency in coral seafloors and otherwise enhance and broaden the Navy's salvage capabilities. Specific criteria are that the anchor be:

(1) directly embeddable into sand, coral, and mud seafloors without the necessity of dragging to embed and set it;

(2) capable of developing a holding capacity of 160,000 pounds horizontal force measured at the hawser of the salvage vessel;

(3) be operational and suitable for use in water depths of 50 to 500 feet;

(4) practicable for use aboard standard U. S. Navy vessels of the ATF, ARS, ASR, and ATS classes in conditions to sea state 4 without the necessity of ship alterations. Auxiliary stowage and handling gear is permissible.

EXPLOSIVE ANCHORS - HISTORY

The term "explosive anchor" has been commonly adopted to designate a type of anchor that is propelled into the seafloor at high velocity by virtue of a rapidly expanding propellant in a gun barrel. Explosive anchors have been under development for over a decade.

At the inception of the explosive salvage anchor program, they had evolved into two basic types. One type with extensible flukes was being marketed commercially in two sizes with rated capacities of 5 and 10 kips, Figure 1. A second type with a shield-shaped anchor-projectile was being marketed commercially by a different company in sizes with rated capacities of 5, 10, and 50 kips, Figure 2. The U. S. Army Mobility

Equipment Research and Development Center (MERDC), formerly U. S. Army Engineering Research and Development Center (ERDL), Fort Belvoir, Virginia, was developing in-house an anchor similar to and actually emanating from the shield-shaped design, Figure 3 (Christians, 1967). NCEL had conducted tests of the two commercially produced anchors for deep water anchoring applications (Smith, 1966 and Dantz, 1968).

The developments with the explosive anchors demonstrated the potential of the explosive anchor concept for salvage operation applications. However, a departure from both types of construction was believed necessary to achieve the stability, ruggedness, and versatility required of a salvage operations anchor and also, to reduce the large recoil distances associated with both existing concepts.

PROGRAM APPROACH

Since a stranding in a location with coral seafloor conditions could occur at any time and result in the expenses and difficulties encountered when the USS FRANK KNOX went aground on coral (NAVSHIPS, 1968), a high priority was designated for the work. The urgency influenced the approach initiated to obtain the new anchor. An explosive anchor tailored as closely as possible to salvage operational requirements was designed with special consideration given to the coral seafloor situation. Supplemental prototype hardware was included in the development program to afford at the earliest moment a capability to cope with strandings in hard seafloor locations.

The design and fabrication of prototype explosive salvage anchors were accomplished by Aero-Jet General Corporation, Downey, California, under Contract N62399-68-C-0002. Prior to delivery of hardware, the contractor conducted testing of prototype equipment utilizing Government-furnished support and facilities. Minor modifications in the design were accomplished by the Contractor as a result of the testing. At the termination of contractor testing, the hardware items specified in the contract were fabricated and delivered to NCEL. Upon receipt of the hardware, NCEL conducted additional testing and accomplished further modifications.

Hardware with ordnance features required strict adherence to ordnance safety. The U. S. Naval Weapons Laboratory at Dahlgren, Virginia was engaged to work with NCEL in this area of the development. Assigned NWL personnel provided safety and reliability criteria for the ordnance features of the salvage anchor design, participated in review of contractor's proposals, and reviewed ordnance designs and hardware at appropriate intervals. During the contractor and NCEL test phases, NWL personnel participated on-site as safety consultants and/or provided guidance through written instructions and recommendations. A Hazard of Electromagnetic Radiation to Ordnance (HERO) test was performed at NWL with a prototype anchor and the design passed this test (NWL, 1969).

EXPLOSIVE SALVAGE ANCHOR DESIGN

General

The explosive salvage anchor constructed to this point is a steel construction comprised of two major features, a reusable launch vehicle and an anchor-projectile, Figure 4. The overall assembly is 12 feet high and has a circular base 10 feet in diameter, and weighs about 12,500 pounds. The launch vehicle supports and orients the anchor-projectile prior to firing, then propels it into the seafloor. The anchor-projectile embeds into the seafloor and becomes an anchor. It is not intended to be retrievable. A piston that inserts into the gun barrel forms part of the anchor-projectile. A prototype coral anchor-projectile with piston is shown in Figure 5. Other features essential to the functioning and application of the explosive salvage anchor assembly include down-haul cables, bridle cable, mechanical cable release device, and ordnance system, Figures 6, 7, and 8.

In operation, the anchor assembly is lowered to the seafloor and fired. As the anchor-projectile ejects, it pulls the mechanical cable release freeing the beach gear leg attachment from the side of the launch vehicle. The down-haul cables trail the anchor-projectile into the seafloor. The launch vehicle then is retrieved for reuse in firing other anchor-projectiles.

In addition to the basic anchor system, two features intended to facilitate the assembling and handling of the anchor on shipboard were designed and fabricated. One feature, a collapsible staging framework, would be stowed aboard the ship in a disassembled state, then assembled to assist in preparing the anchor for firing. The second feature, a simple housing frame to stabilize and position the launch vehicle on deck prior to and after firing, also would be stowed disassembled when not in use. The staging and housing proved not to be necessary and are not discussed further.

Launch Vehicle

The launch vehicle consists of a gun barrel, three hull sections, and three struts that connect the gun barrel and the hull sections, Figure 6. The gun barrel is fabricated from a flanged steel billet with strut attachment bars welded to it. The hull sections are all welded structures that are connected together and to the struts by bolts and gusset plates. Stiffener bulkheads, perimeter ribs, and bottom support frames are incorporated to increase their strength. When assembled the three hull sections form the circular-shaped reaction vessel.

Anchor-Projectiles

There are two anchor-projectiles, one for use in coral and the other for use in sand and mud. The coral anchor-projectile, Figure 5, is a welded, three-fin configuration fabricated from steel. Along the outer edge of each fin are serrations about 2 inches deep and 6 inches long. The anchor-projectile is 6 feet long, the edge-to-edge distance is 37 inches, and it weighs about 2000 pounds with the piston which weighs about 500 pounds.

The sand anchor-projectile for sand and mud, Figures 9 and 10, is constructed of steel and consists of a center shaft and three extensible flukes. The center shift has three ribs welded to it. Each fluke also has a notched rib, Figure 10. The notches mesh and take much of the force due to acceleration. The flukes are in the closed position as the anchor-projectile is propelled into the seafloor. Once embedded and a load is applied, the flukes extend outward to increase the holding capacity of the anchor. The flukes are 5' 6" long, the anchor-projectile assembled for installation has a diameter of 28 inches, and it weighs about 2500 pounds with the piston.

Ordnance System

The ordnance system includes a safe and arm (S/A) device, a touchdown delay firing mechanism and a cartridge assembly. The S/A device initiates the fire train to the cartridge assembly via mild detonating fuze (MDF) leads. Schematics of this arrangement are shown in Figure 8.

The S/A device, Figure 11, contains a pressure-operated in-line/out-of-line slide with electric detonators. The touchdown delay mechanism is activated at the moment the launch vehicle touches the seafloor. After a two-minute delay (this time can be made greater or less) it sends an electric impulse to the S/A device which fires the cartridge via the MDF leads. The delay device recycles if lifted and touched down again.

Miscellaneous Features

An attitude indicator is mounted on the launch vehicle, Figure 8. It emits a signal that is picked up on the ship's depth recorder if the launch vehicle is at an angle greater than 30 degrees. A piston lift and a piston keeper are used to help in inserting the piston in the gun barrel. Detachable ladders are used to help in installing the ordnance features.

Modifications

The design tested by the government reflects several significant changes from the original design produced by the contractor.

Anchor-projectile. An anchor-projectile for mud was part of the contractor's design, Figure 12. It is identical to the sand anchor-projectile except for larger flukes which are 9' 5" long. Its diameter when the flukes are in the folded position for embedment is 36 inches, and its total weight is 3680 pounds.

The original coral anchor-projectile was smaller than the one described, had smooth edges and utilized a bridle arrangement for the down-haul cable, Figure 13. The larger coral anchor-projectile with serrations on its edges and with a swivel connection evolved during testing. For use in rock the coral anchor-projectile was tapered more at the tip accentuating the arrowhead shape, Figure 6.

Ordnance System. The original ordnance system used explosive bolts to release the beach gear leg line from the launch vehicle. Long explosive MDF leads between the S/A device and the bolts were required. The bolts proved unreliable and extremely awkward to install and protect, so they were replaced by the mechanical release device.

The safe and arm device was modified by removing the solenoid used for locking the in-line/out-of-line slide, by removing the attitude indicator, and by potting the electric circuit chamber with room temperature vulcanizing rubber (RTV). Potting the electric circuit chamber was necessary to prevent leakage through the radio frequency gasket (RF) used to seal the chamber. These gaskets evidently deteriorated on the shelf for they had passed hydraulic pressure tests prior to delivery to the government.

Cables and Connections. The down-haul and bridle cables were increased in size from 1-1/4 inches to 1-1/2 inches. The pins that connect the down-haul cables to the bridle cables were changed from standard pins to safety pins with a nut and bolt keeper. An equalizing thimble was installed in the bridle in place of a "spider plate" to assure that loads on the two legs of the bridle are about equal regardless of direction of pull.

Launch Vehicle Hull Section. The hull sections were strengthened by adding stiffener bulkheads, perimeter ribs, and a bottom support frame. Also, pressure relief holes were added. Doubler plates were installed at each structure joint as the hull sections were joined together during assembly.

TEST PROGRAMS

Operations and Procedures

Similar facilities and procedures were used for both the contractor and NCEL testing programs. Exact procedures varied with test objectives and the support equipment available. In general, the anchor assembly was prepared on deck for firing. It was then lifted over the side, lowered to the seafloor and fired. The launch vehicle then was brought back onboard and the vessel being used as a work platform was moved into position to apply test loads to the anchor-projectile.

Loads were applied to the embedded anchor-projectile in one of two ways. One method employed the combined power of the ship plus one or two fleet tugs. The second method involved placing anchors in a spread arrangement, positioning the work platform in between, and applying a load by means of winches or the ship's beach gear. In cases where the projectile did not penetrate enough to develop large holding capacities, it was pulled vertically.

Floating Work Platforms

A variety of floating work platforms were used during the tests. These included the NCEL Warping Tug, a yard freighter utility vessel (YFU) 85 feet long and 25 feet wide, with a tracked crane placed onboard and lashed to the deck, and a Yard Freighter Torpedo Recovery vessel. The primary and most important floating work platforms used in the tests were Navy vessels of the ARS, ATF, and ASR classes.

Instrumentation and Photography

Holding capacities were measured with a 400,000-pound capacity strain indicator fixed securely to a strong fixture on the vessel by means of 1-5/8 inch wire rope. A carpenter's stopper was used to connect the strain indicator to the beach gear leg prior to beginning the test pull. A continuous trace of the load was obtained by a Baushe and Lomb recorder unit.

Except when divers could observe the anchor-projectile after firing, penetration was determined indirectly by measuring the exposed length of the down-haul cable after embedment. This method was approximate due to the difficulty of taking accurate measurements from a moving platform. Conditions prevented measuring the penetration in some tests.

Still and motion photography above and under the water was attempted throughout all testing. Underwater photography was not possible in the sand and mud tests due to limited visibility. In the clear water areas still and motion pictures before and after firing were obtained with hand-held cameras.

For photographing the actual firing, a 4-foot by 4-foot by 4-foot metal framework was used to support a pan and tilt unit with both a motion picture and a television camera mounted on it, Figure 14. The explosive anchor was lowered to the seafloor. Divers positioned the metal framework about 25 feet away from the anchor then left the water. A countdown to fire was initiated and the cameras were activated at the appropriate lead time. Most of the discharges were observed through the TV receiver on deck. No worthwhile video tapes and only two shots of the actual firing of the anchor were obtained. The disappointing results were caused by sometimes faulty connections plus the problem of handling long multiple lines from work platforms that were difficult to maintain in position within tolerable limits during preparations for firing the anchor.

Seafloor Conditions

It was not practicable to obtain bottom samples at each test site. Charts and other documents indicating the general nature of the seafloor in a particular area were employed. The known data about the different seafloors in which tests were conducted are given in Table I.

Tests and Results

The sequence, nature, and locations of tests by both the contractor and NCEL were influenced by the availability of floating and shore support facilities. The contractor conducted a series of tests in sand near Port Hueneme, California, in mud in San Francisco Bay, and in coral near Key West, Florida in that sequence. NCEL conducted testing in rock with basalt characteristics near Anacapa Island, California, in mud at San Francisco Bay, and in coral off the south coast of Oahu Island, Hawaii in that order. Also, NCEL conducted two instrumented tests, Numbers 26 and 27, Table II, to determine gun barrel pressures and anchor-projectile velocities. Further, in support of the State of Washington Oceanographic Commission's Project Sea-Use, a coral type of anchor-projectile was fired into the basalt on top of Cobb Seamount off the coast of Oregon. All tests conducted under the direction of the contractor plus those conducted by NCEL are summarized in Table II.

APPRAISAL OF DESIGN

The emphasis in most all tests was on firing the anchor and determining the holding capacity in a particular type of seafloor. Factors such as the functioning and performance of individual components were observed in conjunction with the primary purpose of each test. Factors such as firing and test pulling the anchor in 500 feet of water and handling and placing it in rough seas were not part of any test. Nevertheless, a valid appraisal of the design can be made by viewing the test program as a whole and considering a specific test, several tests, or all of the tests as they apply to various aspects of the design.

Launch Vehicle

The launch vehicle restricted recoil height to about 8 feet well within the tolerable limit of about 15 feet. Its general configuration provided good accommodation for the down-haul cables and other appurtenances. However, the round hull sections were subject to a wrenching action at each firing that tended to loosen bolts and cause a slight but gradual accumulative distortion.

In one test at Hawaii the struts failed and the gun barrel exited the water. Though the primary cause was the fact that the launch vehicle delivered to the government had not been fabricated in accordance with specifications (Keenan, et al, 1969), the incident emphasizes the need for a better structural shape and larger factor of safety in the structural design. Further, the launch vehicle is too large and heavy. Its round base makes it expensive to fabricate and complicates stowing, assembling, and handling aboard ship. Attaining these improvements in the launch vehicle is a first order priority for on-going development.

Coral Anchor-Projectile

The coral anchor-projectile penetrated coral and developed holding capacities near the 160,000-pound holding objective. Holding action was accomplished under two conditions. In one, the anchor-projectile was embedded to a depth such that the cable and cable connection remained clear of the seafloor-water interface. In this condition the load component was largely in a horizontal direction and tended to overturn or rotate the anchor. In the second condition the anchor-projectile was embedded to a depth such that the cable connection was below the seafloor-water interface, Figure 15. Here, the load component on the anchor was primarily vertical tending to extract the anchor straight upward. The anchor-projectiles suffered negligible damage due to the penetration and load applications in coral.

At the Anacapa Island test site a coral anchor-projectile, modified by making its tip more pointed, Figure 6, penetrated the rock to a depth of about 54 inches and developed a holding capacity of over 160,000 pounds. The test specimen suffered negligible damage as a result of the test. In the subsequent operation in basalt at the Cobb Seamount the anchor-projectile penetrated the rock about 30 inches but was damaged in the process. Holding capacity was seriously reduced as a result of the damage.

In general, the coral anchor-projectile performed satisfactorily and showed promise of broader application than the originally specified ability to function in coral. By changing the configuration and heat treating the edges to harden them it is believed that a version of the coral anchor-projectile can be made functional for use in some types of rock as well as in coral.

Sand/Mud Anchor-Projectile

The sand anchor-projectile and the original mud anchor-projectile with the large flukes were successfully fired into the seafloor without being damaged. Penetration to about 18 feet and a holding capacity of over 100,000 pounds were achieved in sand. However, penetrations inadequate to allow the flukes to open also were experienced.

To understand the difficulties with extensible flukes it is necessary to examine how they function. The flukes are aligned in a vertical position during the penetration phase of the placement procedure. After attaining the maximum embedment as a result of the kinetic energy imparted to them, they are pulled back up toward the seafloor-water interface to get the flukes to extend outward. The distance required for the flukes to open can vary from at least 1 to more than 1-1/2 times the length of the flukes. Much of the effectiveness of penetrating into the denser lower levels of the seafloor is lost during the fluke-opening process. The large-sized flukes intended for use in mud proved to be too awkward and bulky to be practical. Also, tests indicated the potential gain in holding capacity due to fluke size is offset by the lesser penetration attainable and the large vertical distance required to "key" the flukes to the outward position.

The ability to fire the fluked anchor-projectiles without incurring damage is significant. In early designs not associated with this program, anchor-projectiles with extensible flukes and having rated capacities greater than 10,000 pounds nearly always sheared off or were severely damaged during firing and penetrating.

Though the design technique of the notched webs, Figure 10, to lessen stress on the pins was successful in eliminating damage while propelling large-sized flukes at high accelerations, the reliability of functioning is low due to the generally excessive resistance to penetration of sand seafloors and the large upward movement needed to get the flukes to extend outward. Such penetrations and holding capacities are examined theoretically in Appendices A and B. Thus, further work is needed to improve the fluked anchor-projectile design to obtain greater penetration and a more efficient keying action that minimizes uplift displacement. Preliminary investigation indicates that such design improvements can be attained.

Ordnance System

The modified safe and arm device did not leak and proved workable with both an electrical cable and the touchdown delay mechanism. However, it is unduly complex and expensive to be an expendable item, employs electric initiators which must be shielded from hazard by electro-magnetic radiation, and employs mild detonating fuze (MDF) leads to fire the cartridge. The MDF leads are awkward and time-consuming to install. After they are in place they are highly susceptible to being pulled apart or otherwise separated prior to firing the propellent.

The electrical firing cable devised by the contractor worked well in the shallow depths of the tests. However, it constitutes a third line to be handled and at depths beyond 200 feet, problems of entanglement and damage increase drastically.

The touchdown delay firing mechanism eliminated the third line problem and was able to withstand the shock of firing the anchor. However, it imposes restrictions on the salvage vessel movement if the delay process is to be of any value in lifting the anchor before firing to reset it or to retrieve it. This constraint would be difficult to achieve by an unmoored salvage vessel attempting to place the anchor in a moderate or rough sea.

A fire control and command system that does not require an electrical connection or that does not require precise ship positioning such as is now needed for the touchdown delay mechanism would be an asset. An acoustic command system seems to offer a potential solution and bears investigation for possible incorporation in the design in the future.

Though no malfunctions traceable to the cartridge rounds were experienced, they are awkward to assemble and handle and generally are unsatisfactory for service use. Standardizing them as much as possible as to size and type of propellant for future use with the different anchor-projectiles would be a decided advantage.

Cables and Connections

Damage due to rapid payout during ejection of the anchor-projectile was negligible. In one instance damage to the down-haul cable resulted from the launch vehicle falling back down on the cable. Still, the cable did not fail during short time loading.

The mechanical device used to release the beach gear leg and down-haul cable from the launch vehicle, Figure 7, was a significant improvement over the explosive bolt release system. No evidence of its failure to function was recorded. However, the cable that attaches to the anchor-projectile and pulls the release bar is susceptible to damage as it penetrates hard seafloors. If it should break the release would not take place. Also, the cable release is exterior to the launch vehicle hull section and can be damaged if it strikes the side of the ship during launching.

A serious consideration in the design and use of explosive anchors is that the cable(s) that follows the anchor-projectile into the seafloor is subject to abrasion and is more susceptible to deterioration by corrosion than is the chain. The 1-1/2-inch cables used in the tests did not fail but they were not subjected to long-term abrasion or exposure to the environment. Means to lessen or circumvent these adverse effects need to be explored.

Deep Water Placement

In Test 30, the explosive salvage anchor was set on the seafloor and retrieved in 600 feet of water. To accomplish this operation, the beach gear leg was laid before the anchor was lowered. A crown buoy was attached to the bitter end of the beach gear leg with a synthetic line. Next, the crown buoy, synthetic crown buoy line, and the beach

gear leg were deployed in succession. Then the anchor assembly was lowered with 1-inch wire rope leading from the port drum of the winch and fairled over the port side of the ship.

The operation showed that though the anchor can be placed in deep water, special rigging arrangement is required with existing ship equipment. The size and weight of the launch vehicle imposed severe conditions on the handling equipment. A lighter launch vehicle with less drag through the water during retrieval would be an asset.

DISCUSSION

The present design as modified through testing partially fills the void in anchoring capability for salvage operations that currently exists as a result of inherent limitations of conventional anchors. The anchor can be directly embedded without a preset pull operation in hard seafloors such as coral and it will develop holding capacities that exceed the strength of a standard beach gear leg. Also, by employing a different type of anchor-projectile it can be set in sand and mud seafloors though the holding capacity and reliability of functioning in these seafloors is less than in coral. However, significant further development is required before the broad operational and performance goals set at the beginning of the program can be attained.

Explosive anchors and conventional anchors each possess inherent characteristics that currently appear to give each type exclusive advantages over the other in individual situations. Prominent advantages of the explosive type of anchor are its ability to penetrate directly into the seafloor, to resist uplift loads and loads from all directions, and to function in hard seafloors such as coral. Prominent advantages of the conventional type of anchor are its simple construction and the fact that the force applied to it tends to embed it further rather than to extract it (in the case of explosive anchors, the force is opposite in direction to the embedding force). Also, the capability to use chain with conventional anchors greatly reduces abrasion and wear of connective gear, thus increasing service life. Another fact pertinent to all anchors is that their efficiency as measured by holding-capacity-to-weight-ratio goes down as size increases. This factor is especially important in the design of explosive anchors because of the energy required to accelerate a large mass.

Limited amounts of hardware of the present design are stored at NCEL and available for emergency use. Drawings and specifications for the procurement of additional items and an interim operations manual have been prepared (NAVSHIPS Technical Manual, 1970). However, further minor refinements of the design are advisable to improve its handling, functioning and reliability. An attachment package to support and/or protect the touchdown firing mechanism, the explosive (MDF) leads and the downhaul cables and a retainer to keep premature force off of the shear pins used to secure the anchor-projectile against the gun barrel prior to firing are needed. The cable release mechanism should be improved by eliminating the need for the release bar pull cable, Figure 7.

Major modifications of the present design are not practicable because improvements are needed that cannot be accommodated with the existing hardware. The two features of the design where improvements would be most immediately beneficial are the launch vehicle and the ordnance system. The launch vehicle needs to be made smaller and less heavy for handling, placing and retrieving. Also, it needs to be better configured for ease and economy of constructing and assembling and for better structural integrity. A launch vehicle constructed of standard straight steel shapes appears to be feasible. The safe and arm device needs to be simplified, miniaturized, made less expensive, and the mild detonating fuzes eliminated. Work on the design of a new launch vehicle and S/A device to obtain in these improvements has been initiated.

Improvements in these two features would increase the practicality and expand the range of capabilities of the explosive salvage anchor. The original goals need to be re-examined and realistically appraised as to the priority of salvage anchor capabilities.

As visualized at the inception of the program, the explosive anchor would be a standard shipboard item and would supplement or even supplant the standard EELLS anchor as the salvage anchor. In normal cruising it would be in a disassembled state and stowed on salvage vessels in locations that minimize interference with normal ship routine. When a salvage situation developed, the explosive salvage anchor would be brought to a readiness state as the salvage vessel proceeded to the salvage site.

A possible operational concept would be to have the explosive anchors in pools at strategic locations. The anchors and quickly-mountable accessory handling gear could be picked up by salvage ships or transported to them by air. The conventional EELLS anchors would be retained as standard shipboard gear and the explosive anchors would be used in hard seafloors and/or for direct emplantments where presetting pulls and displacements are intolerable.

The performance requirements would have the anchor capable of functioning in hard seafloors such as coral and capable of developing holding capacities of 100,000 pounds, i.e., the approximate capacity of a Navy beach gear leg, vice 160,000 pounds. Full functionability in sand and mud seafloors would be a secondary requirement to be attained later. The performance criteria for operating in rough seas and to depths of water of 500 feet would remain the same.

An improved explosive salvage anchor design emanating from the proposed new launch vehicle and ordnance system should meet or exceed these revised operational and performance criteria. Thus, it would fulfill a required capability in the near future and provide a well-established base from which to ultimately expand capability to the original goals established. Future work would include improving anchor-projectile designs for use in all types of seafloor and achieving a better more reliable means of controlling the firing, such as with an electro-mechanical cable.

CONCLUSIONS

1. An explosive anchor for salvage operations has been demonstrated to be workable and feasible.

2. A design has been attained that meets the particular urgent need for anchoring capability in coral seafloors.

3. Minor improvements in the existing design are needed to enhance its functioning and reliability for use in emergency situations.

4. Major redesigns of the launch vehicle and ordnance system are needed to achieve broader capabilities and make the explosive salvage anchor acceptable as standard salvage gear.

RECOMMENDATIONS

1. Improve the existing hardware by designing a unit package for attachment and protection of the attitude indicator and S/A device, by devising a method to relieve premature pressure on the shear pins, and by modifying the mechanical cable release.

2. Redesign the launch vehicle to reduce it in size and weight, to improve its configuration for fabricating, stowing, handling, and placing, and to improve its structural integrity.

3. Redesign the ordnance system to reduce the size of the safe and arm device and make it more reliable and less expensive and to eliminate the use of mild detonating fuzes in the firing train.

ACKNOWLEDGMENTS

The Naval Weapons Laboratory at Dahlgren, Virginia provided valuable guidance and consultation on the ordnance safety aspects of the design, testing, and appraisal. In particular, the exceptional cooperation and significant contributions of Mr. Stuart McElroy and Mr. Bud Troxall of NWL are recognized.

Outstanding support and cooperation was received from various ships and activities throughout the test program. Recognition of and appreciation to these organizations are expressed in the approximate chronological order of their participation. Some were involved in more than one phase of the testing.

Officers and Crew of USNS GEAR
San Francisco Bay Naval Shipyard, Public Works Department
Naval Photographic Division, Point Mugu, California
Naval Ordnance Station, Key West, Florida
Officers and Crew of USS PENGUIN
Officers and Crew of USS SIOUX
Officers and Crew of USS GRAPPLE

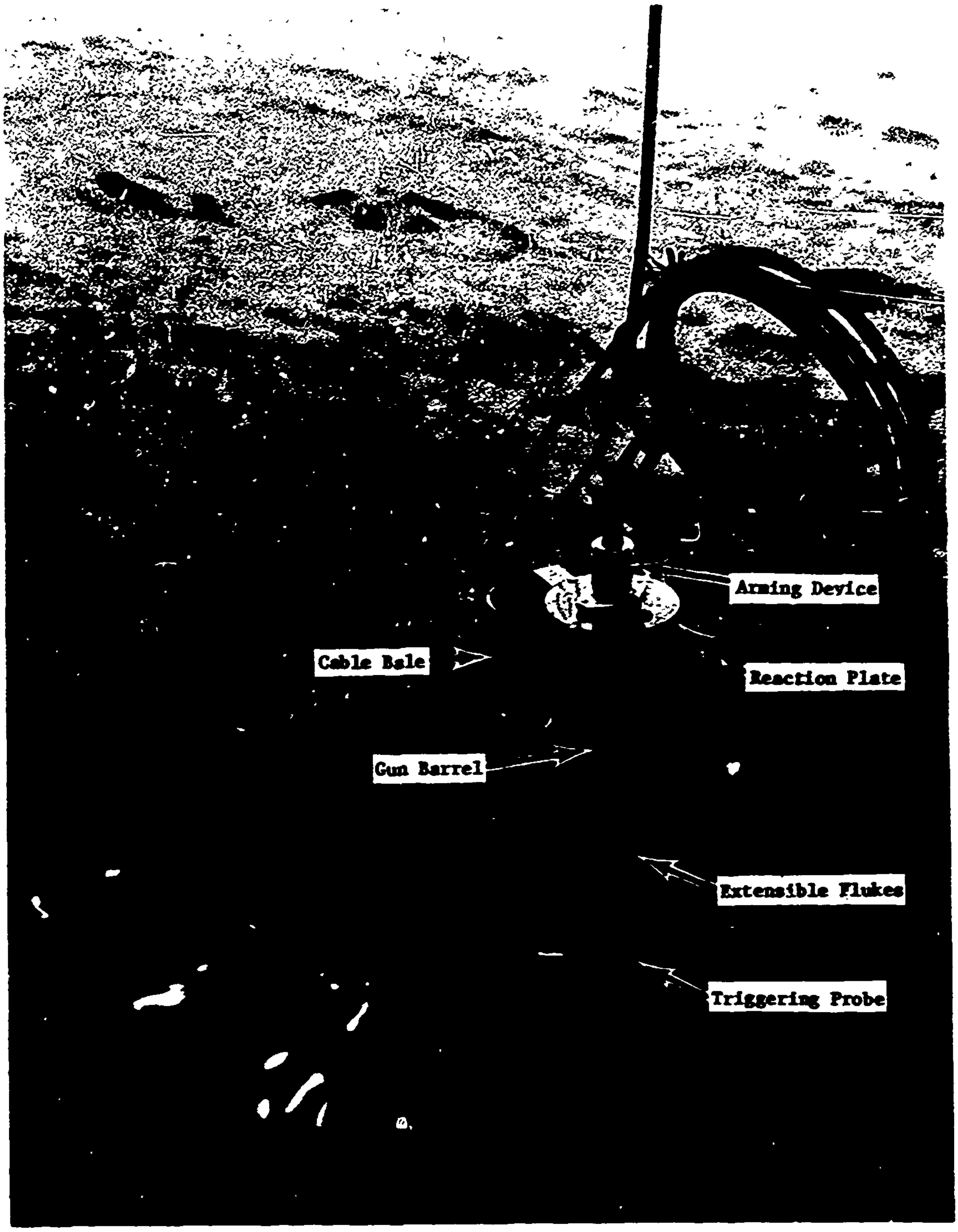

Figure 1. Small Explosive Anchor with extensible flukes.

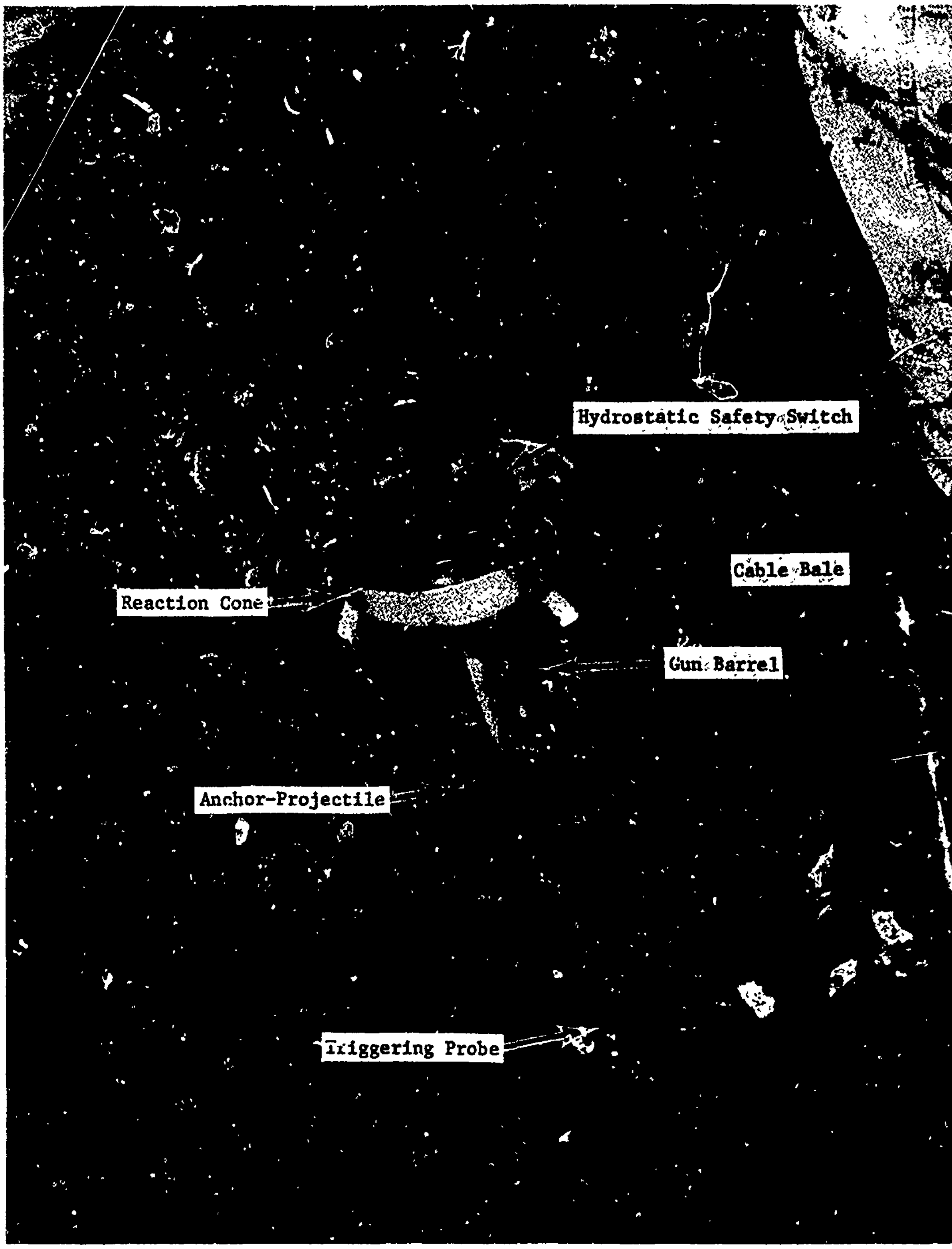

Figure 2. Small Explosive Anchor with shield shaped anchor-projectile.

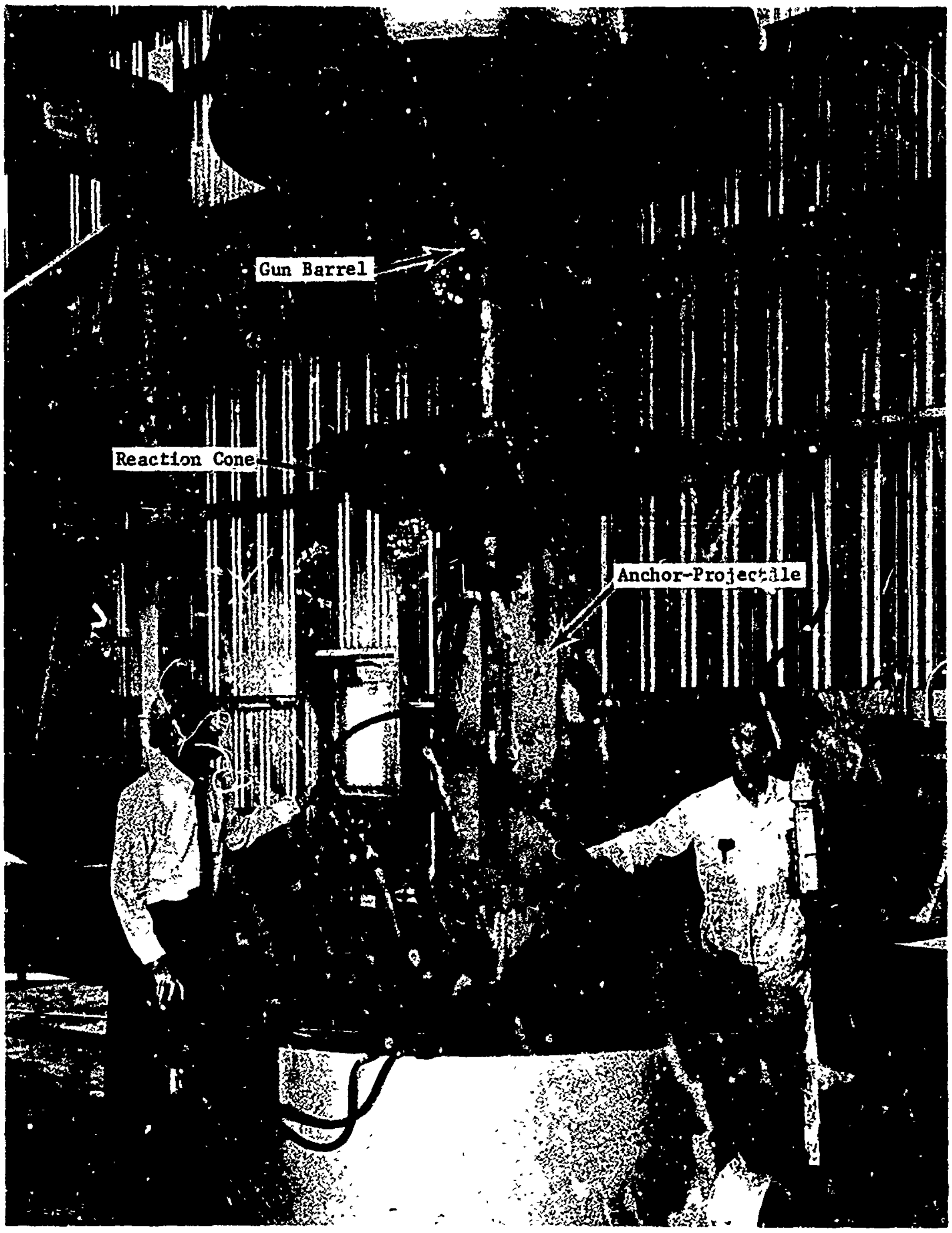

Figure 3. MERDC 50-K Explosive anchor.

NOT REPRODUCIBLE

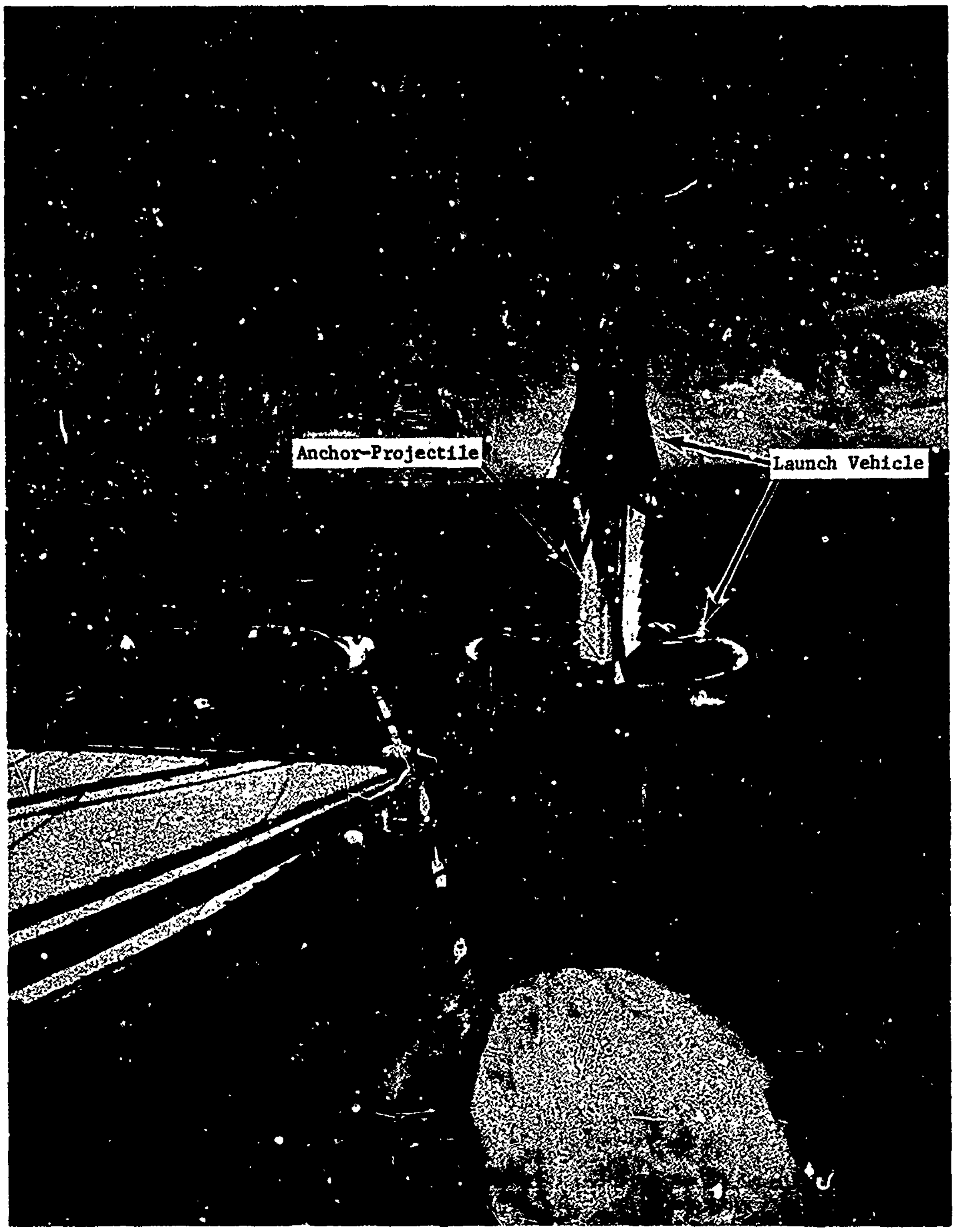

Figure 4. Explc ive Salvage Anchor Assembly with Coral Anchor Projectile.

Figure 5. Coral Anchor-Projectile with piston.

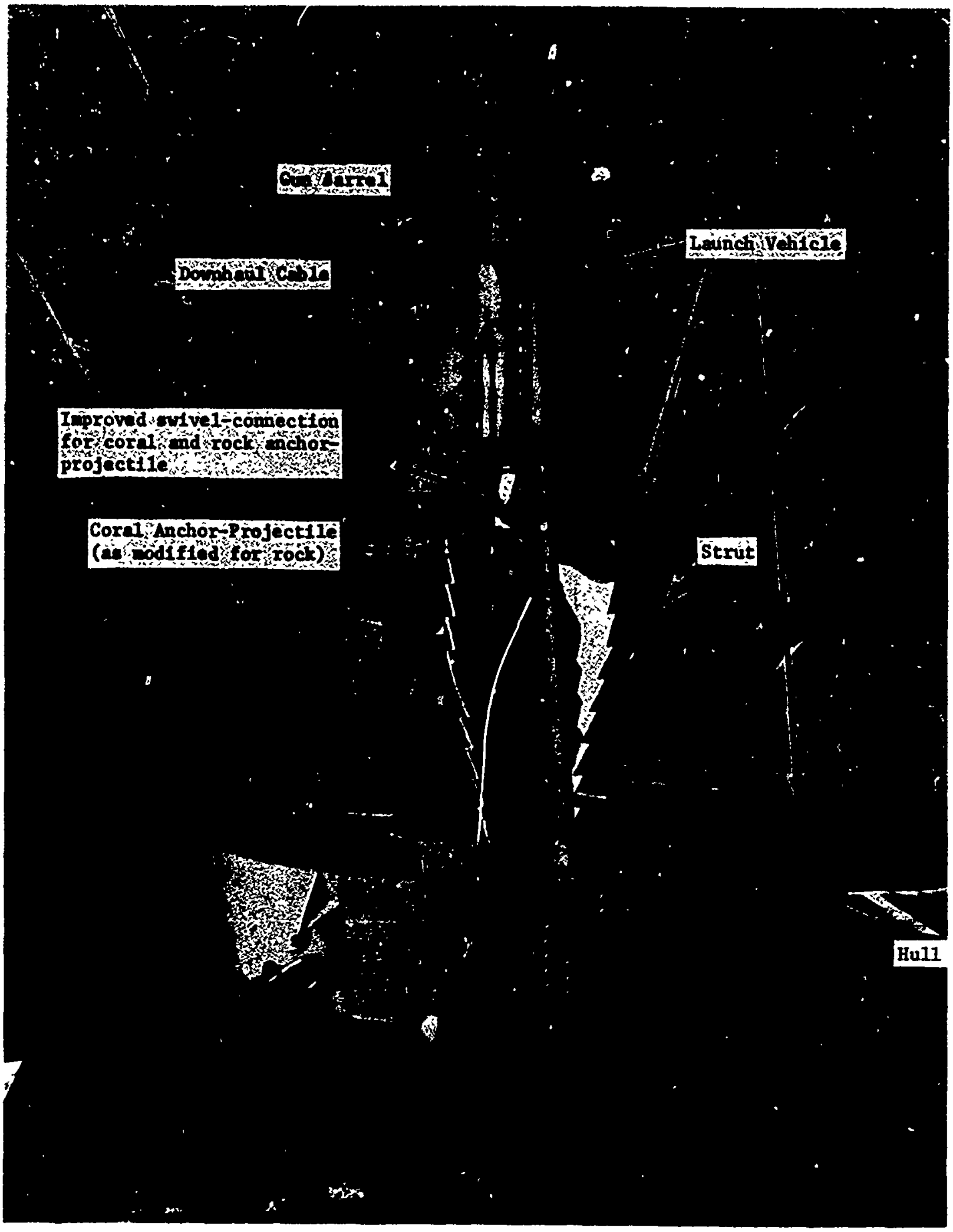

Figure 6. Anchor Assembly with Coral Anchor-Projectile as modified for rock.

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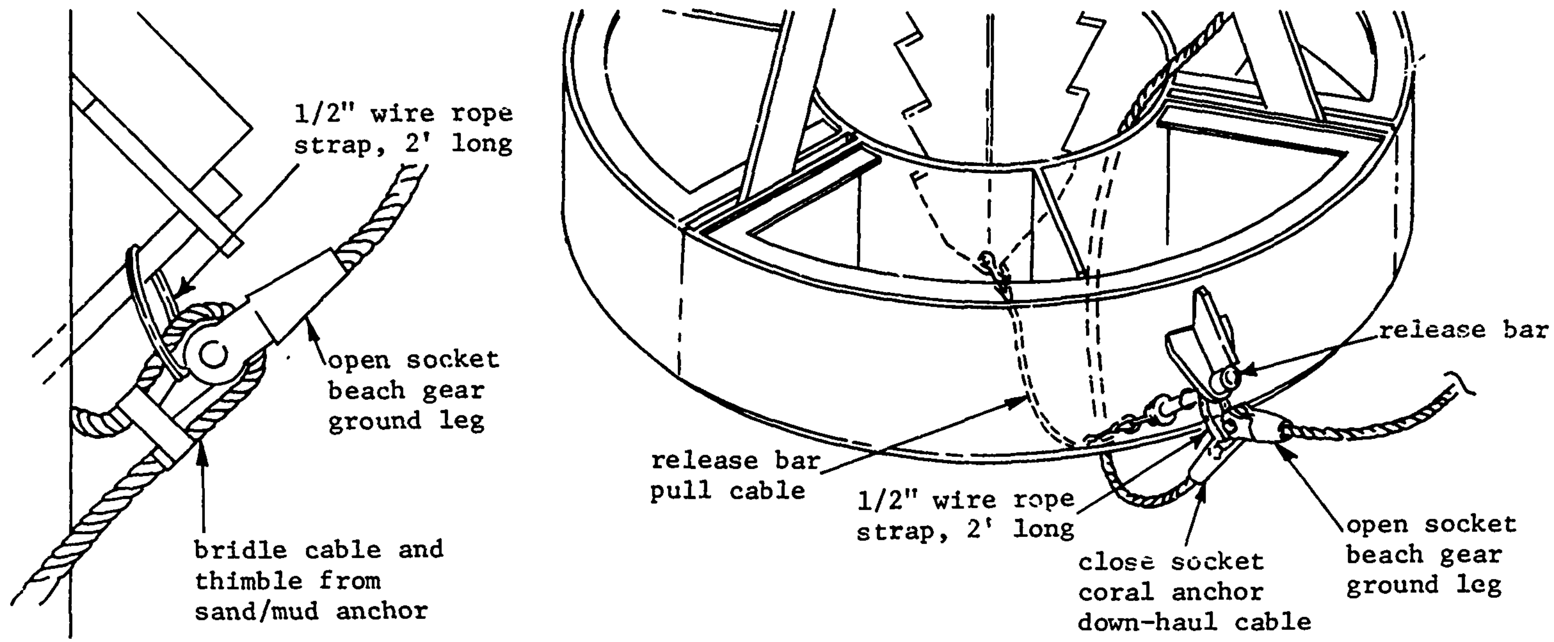

Figure 7. Schematics showing bridle cable and mechanical release device.

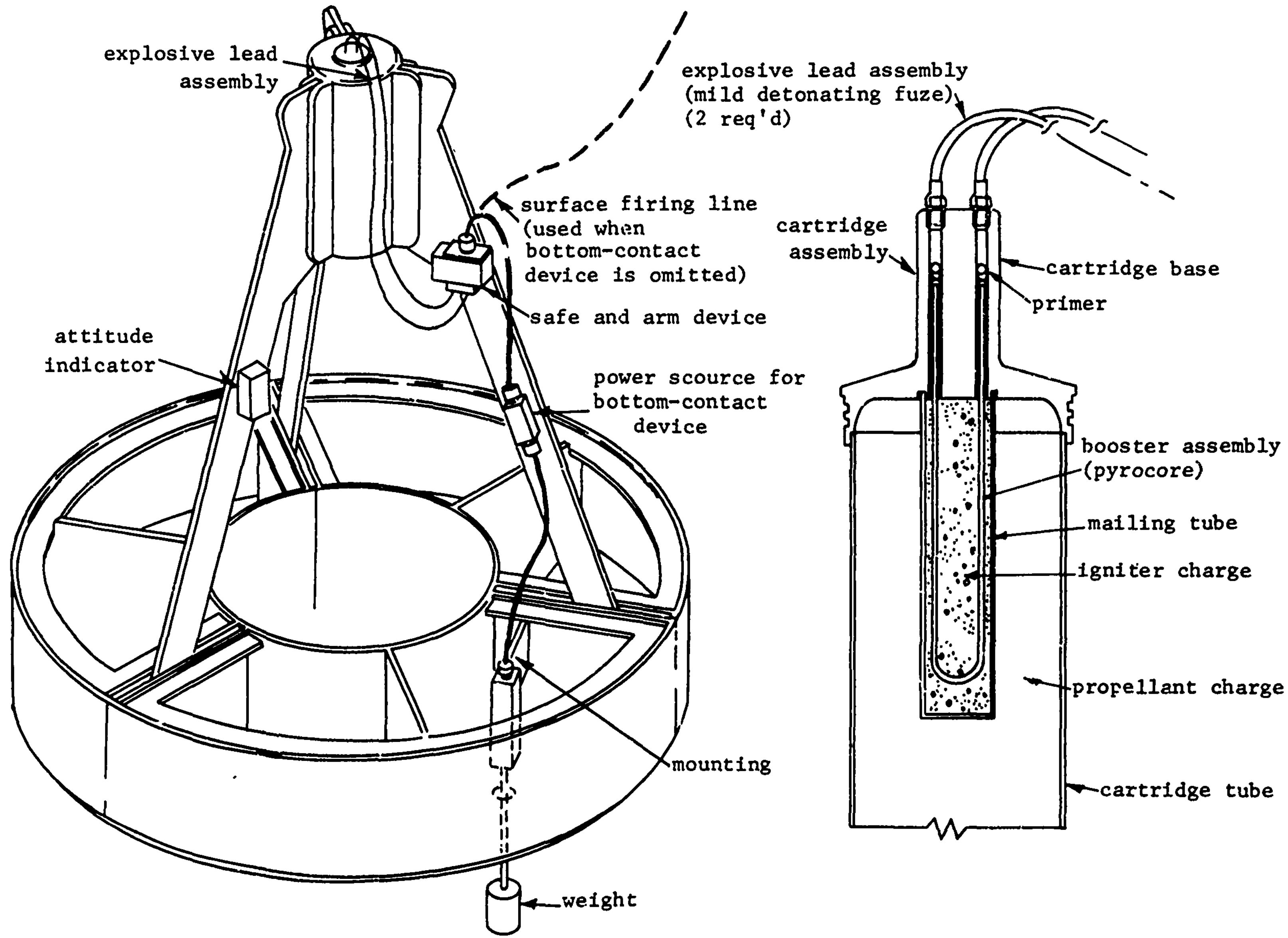

Figure 8. Schematic of Ordnance System.

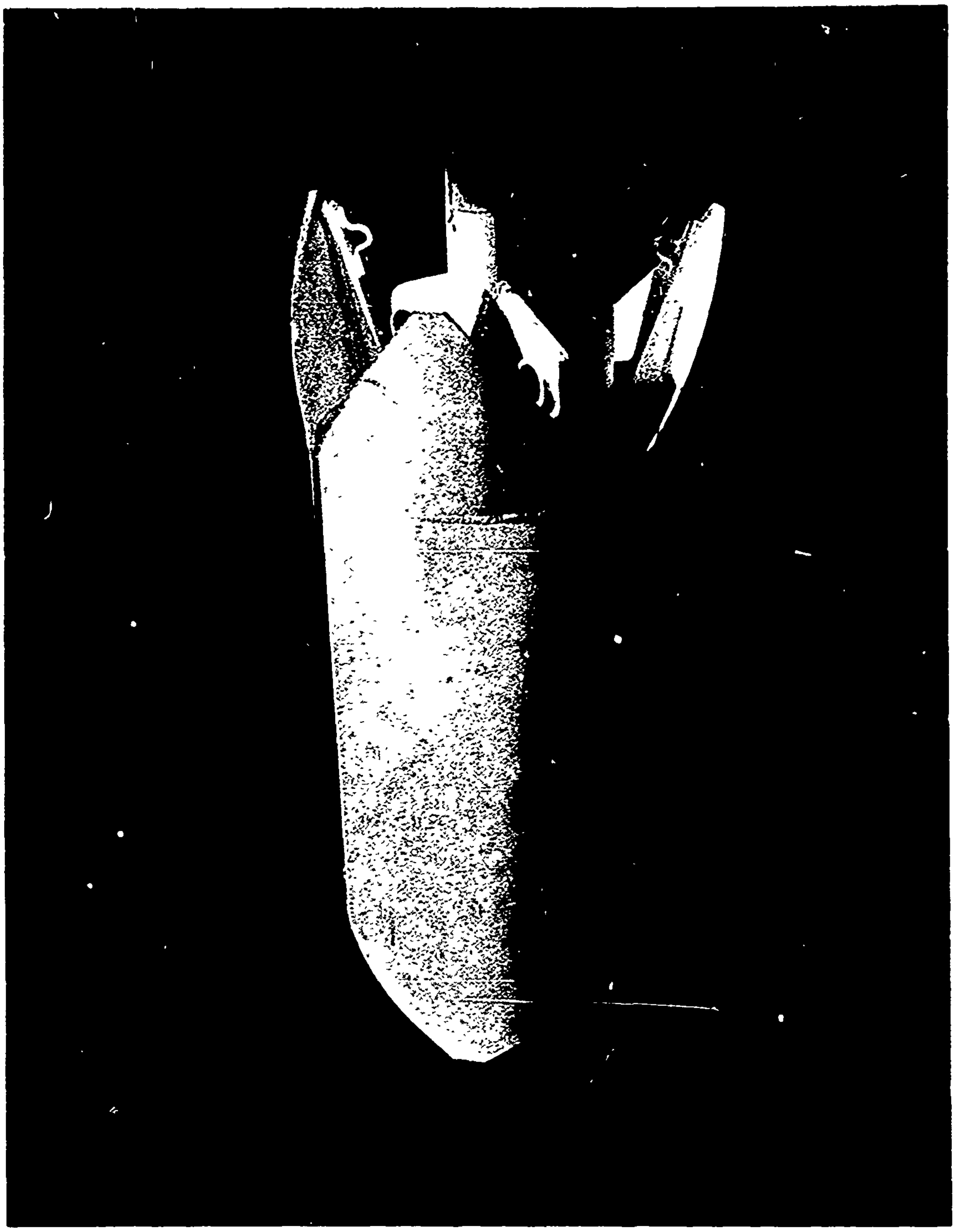

Figure 9. Sand Anchor-Projectile (Flukes Closed).

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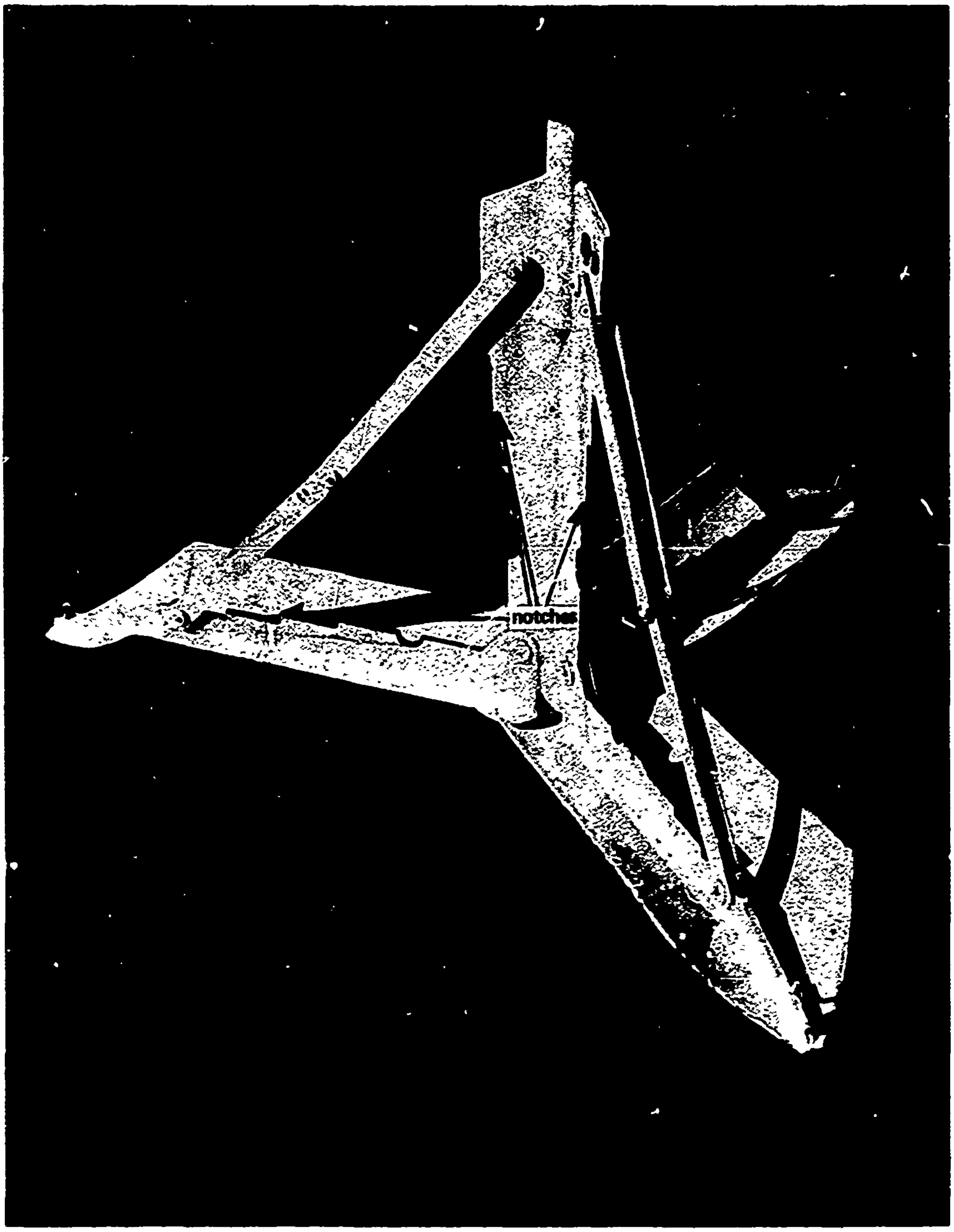

Figure 10. Sand Anchor-Projectile (Flukes Extended).

NOT REPRODUCIBLE

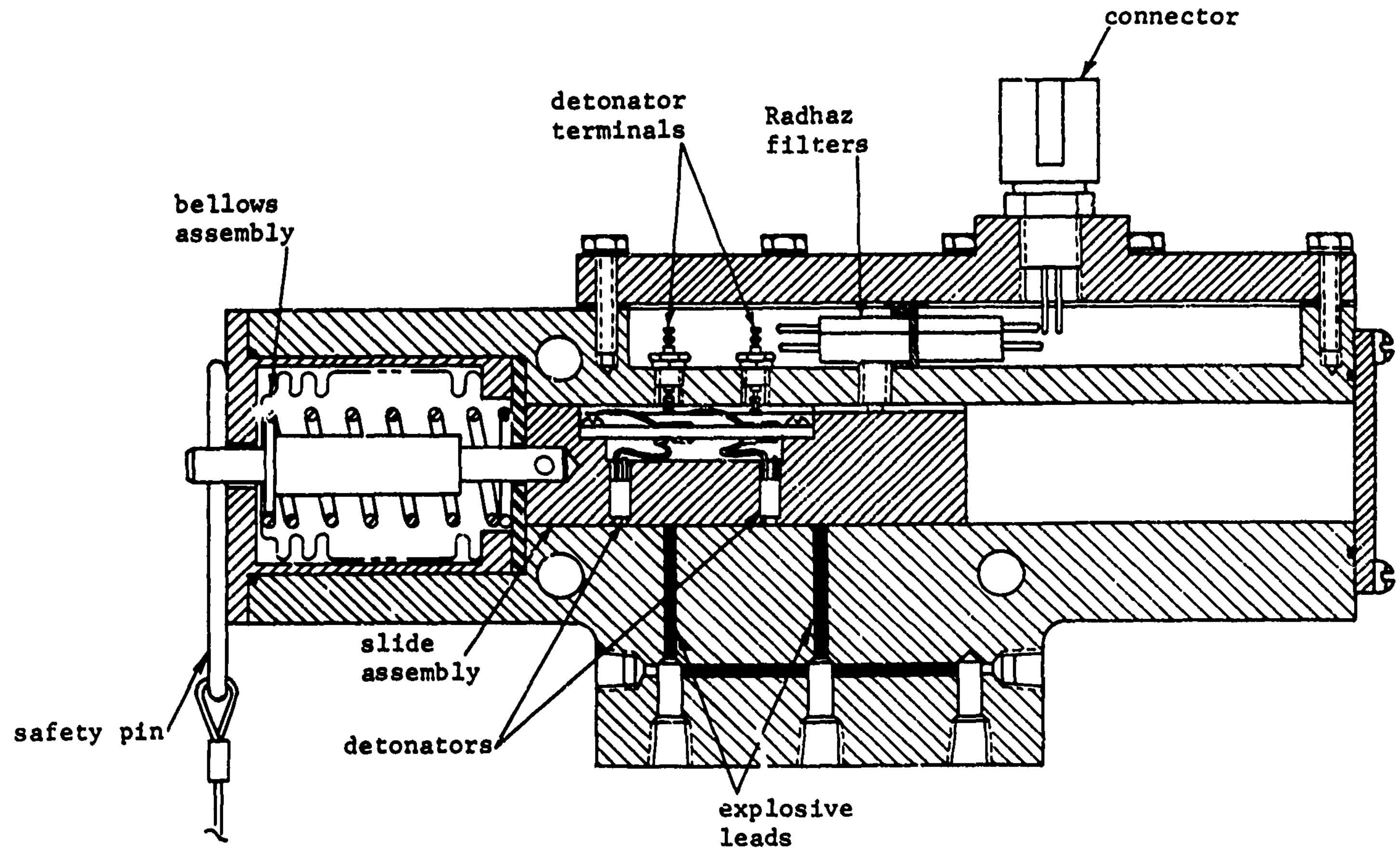

Figure 11. Sketch of safe and arm device.

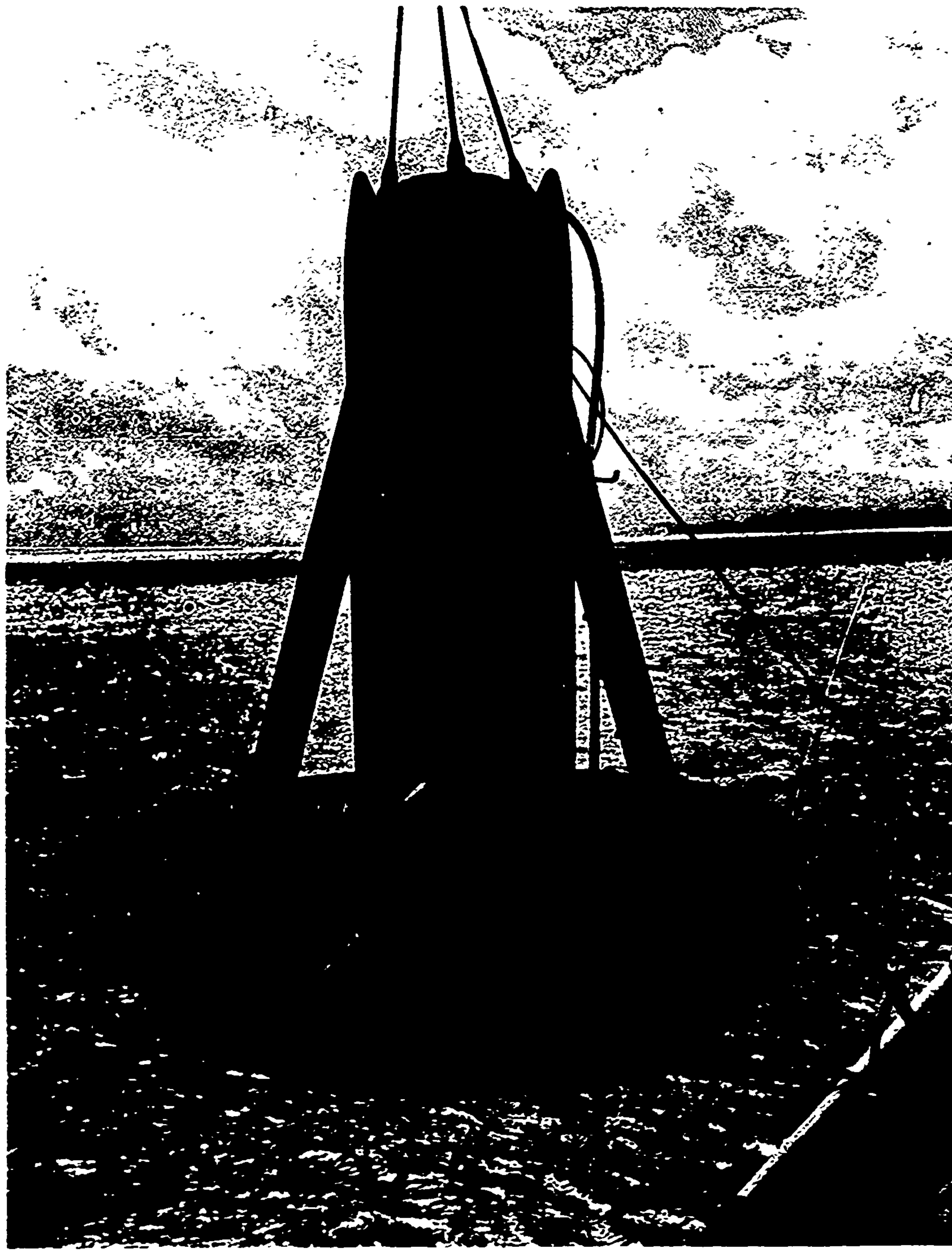

Figure 12. Explosive Salvage Anchor with original mud anchor-projectile.

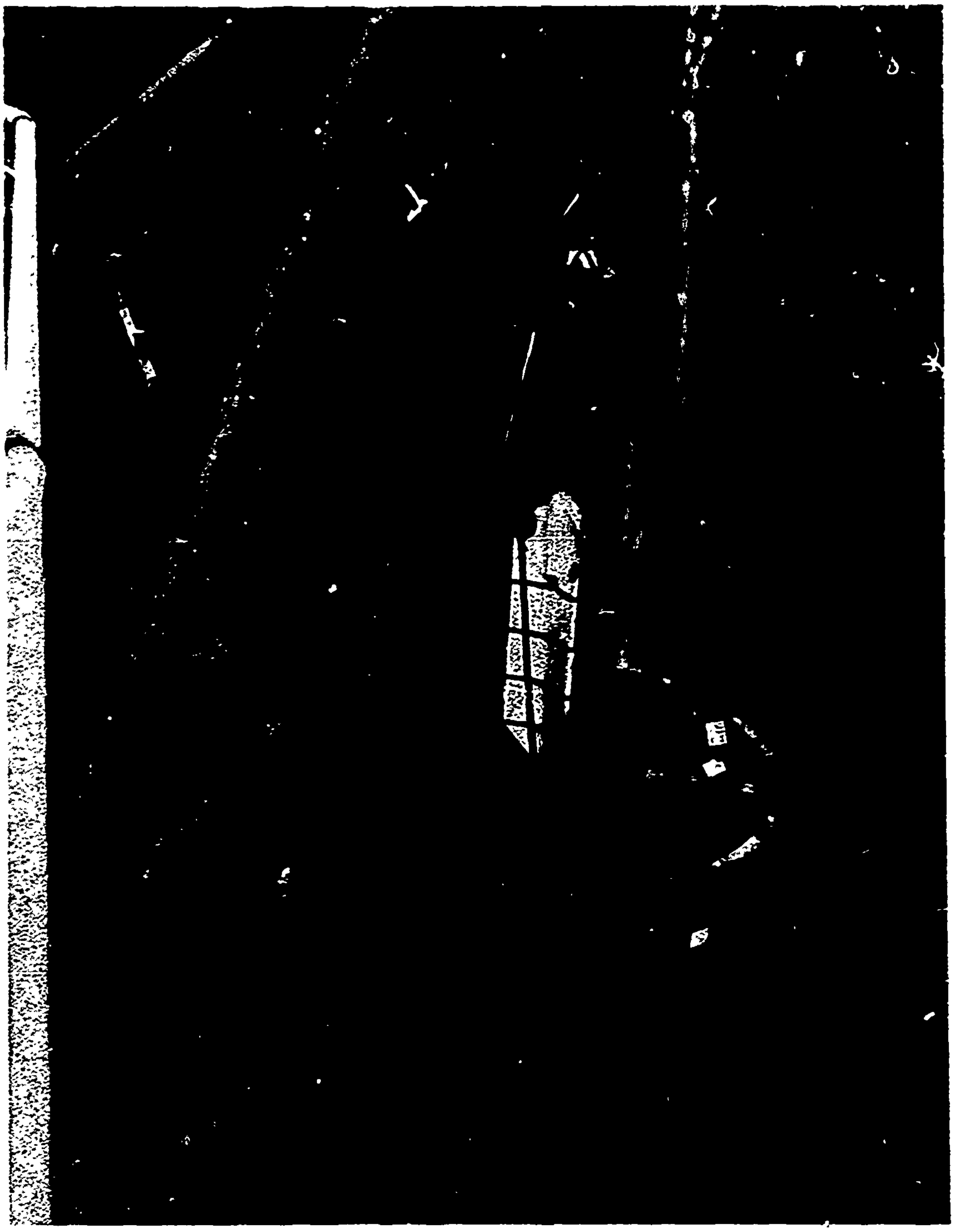

Figure 13. Explosive Salvage Anchor with original Coral Anchor-Projectile.

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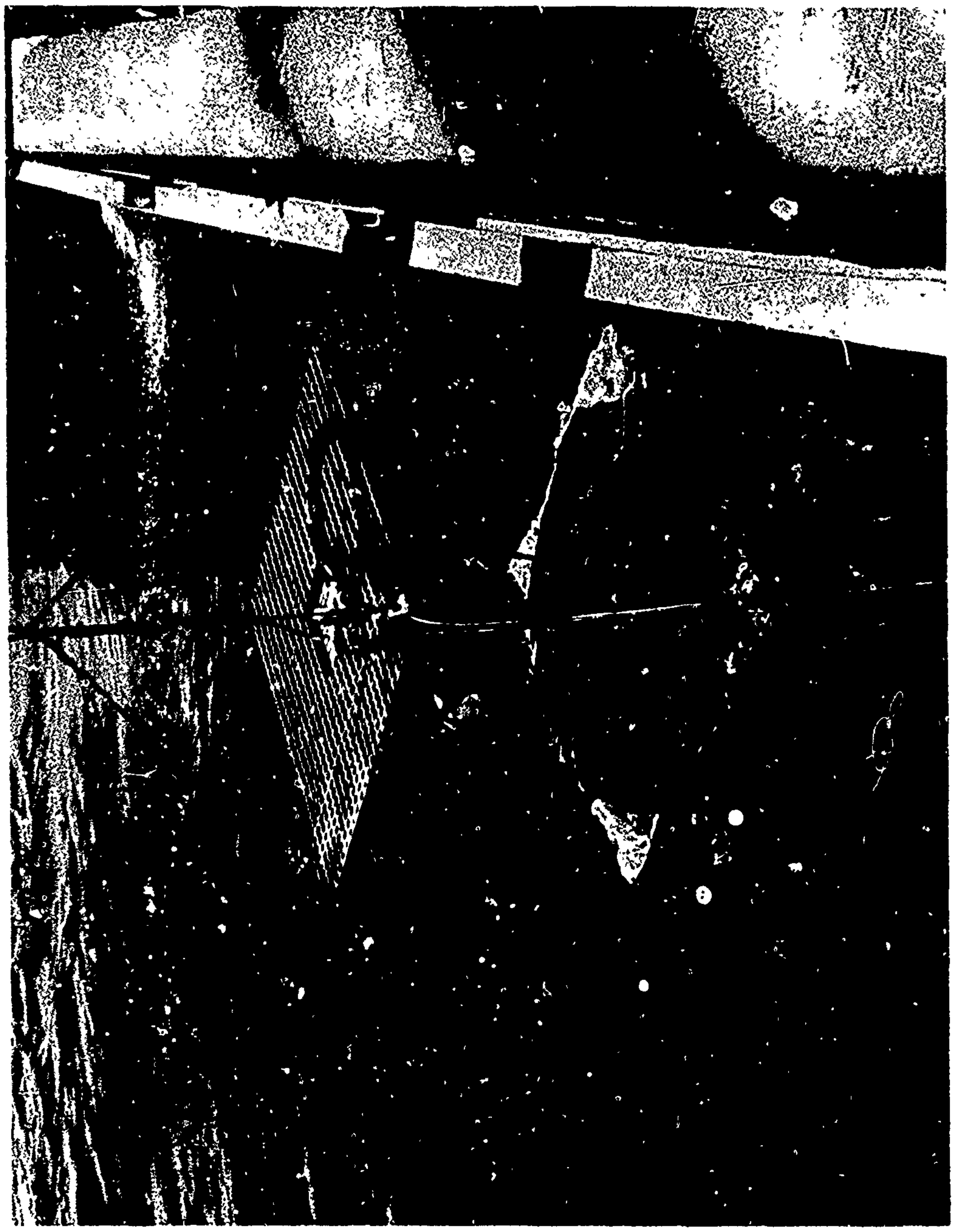

Figure 14. Pan and Tilt camera and television equipment.

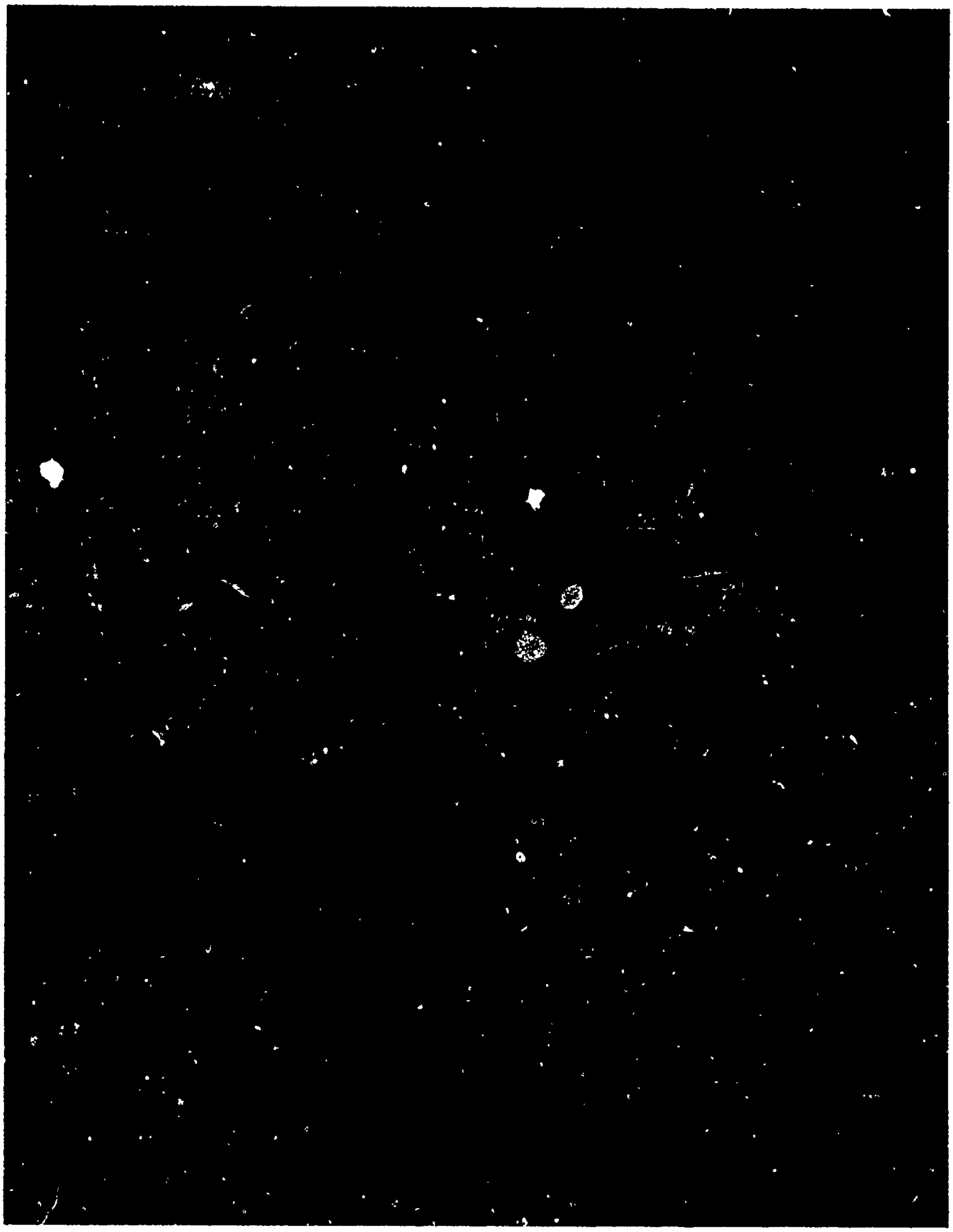

Figure 15. Coral seafloor with Anchor-Projectile fully embedded.

NOT REPRODUCIBLE

Appendix A

ANCHOR PENETRATION INTO SOIL

by D. G. True

The following discussion is presented to show variation in the penetration behavior, and especially the ultimate embedment depth, which can be expected to result from variations in soil properties and projectile configurations. Although the basic equations for penetration behavior and the assumptions used in evaluating coefficients for those equations are open to serious question (indeed, they are the subjects of current and planned research), it is felt that they are sufficiently well understood to support calculations for the purpose of indicating the importance of the various aspects of anchor geometry and soil deformation which contribute to penetration resistance and the potential value of possible projectile modifications.

An equation developed by Poncelet in 1839 to predict penetration is

$$-m\frac{dv}{dt} = \alpha + \gamma v^2 \tag{A-1}$$

where
- m = mass of projectile ($FT^2\ L^{-1}$)*
- t = time (T)
- v = velocity of projectile (LT^{-1})
- α, γ = material property coefficients (F)

To predict penetration of projectiles into soils, Equation A-1 takes the form

$$m\frac{dv}{dt} = -sN_cA_F - \delta_a sA_s - \tfrac{1}{2}\rho\, C_DA_Fv^2 \tag{A-2}$$

where
- s = soil shear strength (FL^{-2}) (may vary with depth)
- N_c = bearing capacity factor (known function of soil friction angle)
- δ_a = adhesion reduction faction
- A_s = side area of projectile (L^2)
- A_F = frontal area of projectile (L^2)

---

*F, L, and T represent generalized units of force, length, and time, respectively.

ρ = mass bulk density of soil (FT^2L^{-4}) (may vary with depth)

C_D = drag coefficient of soil (essentially constant for turbulent flow)

in which penetration resistance is expressed as a combination of static shear and inertial drag resistance (Christians and Meisburger, 1967; Thomason, et al, 1968; and Schmid, 1969).

By integrating Equation A-1 twice with the initial conditions $t = 0$, $v = v_o$, and displacement, $x = 0$, the final maximum penetration, x_{max}, can at a final velocity, $v = 0$, be calculated as

$$x_{max} = \frac{m}{2\gamma} \; (1 + \frac{\gamma v_o^2}{\alpha}) \tag{A-3}$$

The relationships for the constants α and γ in Equation A-2 are used as input for Equation A-3 to obtain, for a homogeneous sediment,

$$x_{max} = \frac{m}{\rho C_D A_F} \ell n \; (1 + \frac{\frac{1}{2} \rho C_D A_F v_o^2}{s N_C A_F + \delta_a s A_s}) \tag{A-4}$$

This relationship provides a basis for predictions of penetration depth for anchor-projectiles of various configurations into various types of soils. For cohesive materials such as clay, the expression is directly applicable. The shear strengths of terrigenous sea floor clays have been observed to range from 0.2 psi at the surface to 3.5 psi at 10 feet (Taylor and Demars, 1970; Demars and Taylor, 1971). Extrapolating these results to the embedment depths of interest (0-30 feet) gives a range for clays of 0.2 to 5 psi. The adhesion reduction factor, δ_a, is considered to be the inverse of soil sensitivity which averages about 2.5 for typical clays; therefore δ_a would average 0.4. For sands, the fact that penetration is too rapid to permit drainage of pore water causes the pore pressure to change in accordance with the tendency of the sand to dilate or compress during shear. Loose sands tend to compress and dense sands tend to dilate producing positive and negative changes in pore pressure, respectively. Such a pore pressure change acts together with the in-situ static overburden stresses to cause the undrained effective confining stress to reach a critical value ($\sigma' = \sigma'_{crit}$) after a shear strain of several percent. The magnitude of this critical confining stress depends upon the void ratio (density) of the sand during the undrained (zero-volume-change) shearing. Thus, the strength of a saturated sand when the penetration is so rapid as to prevent drainage of the sand may be represented as

$$s = \sigma' \tan \phi = \sigma'_{crit} \tan \phi \tag{A-5}$$

where s = shear strength (FL^{-2})

σ' = effective confining stress (FL^{-2})

σ'_{crit} = critical confining stress (function of in-situ void ratio) (FL^{-2})

ϕ = angle of internal friction (degrees)

Considerations of the critical confining pressures for various sands (Seed and Lee, 1967) and of the water depths causing equivalent hydrostatic pressures which must be overcome to produce cavitation of pore water indicates that for typical sands (relative densities between 30 and 60 percent) and for locations of interest here (water depths between 50 and 500 feet), the effective confining pressure during rapid shearing will be on the order of 1.5 to 10 kg/cm^2. For friction angles of 25 to 45 degrees (corresponding to the above relative densities) shear strength as computed from Equation A-5 ranges from 0.7 to 10.0 kg/cm^2, or 10 to 140 psi.

Implementation of the above relationships in the calculation of depth of penetration requires the exercise of judgment in selecting values of soil property coefficients. If a homogeneous sediment is assumed, average values must be estimated for a guessed maximum depth of embedment, and revised in a subsequent iteration if the guessed depth is too much in error. Alternatively, Equation A-2 can be solved incrementally, with values of soil property coefficients which are specified functions of depth and/or velocity; this has been done successfully at NCEL under a separate study. Pertinent projected areas during embedment of the existing SUPSALV sand anchor-projectile are given in Table A-1 for the purpose of estimating its penetration behavior. Estimates of the ultimate penetration depth of this projectile for typical conditions are given in Table A-2 as computed from the relationships derived above. According to these estimates, the present sand anchor-projectile launched with the present launching system will not penetrate sufficiently in medium-dense to dense sands to key (the sand fluke requires a distance at least equal to 2 times its length to key) and hold with usable capacity (at least 12 feet of embedment after keying are required for satisfactory anchor holding performance). The bulk of experimental data obtained to date on the penetration of this projectile in sands indicates that these estimates are somewhat low; penetrations to 10 feet in sand (still insufficient for satisfactory holding performance) have been achieved along with one penetration to 18 feet in a reportedly sandy soil of undetermined composition. On the other hand, experimental penetration depths in seafloor clays of determined strengths have been on the order of the predicted depths. Apparently, the equations or assumed coefficients used to estimate penetration in sands are not altogether accurate. However, the quantitative agreement between experiment and theory on the insufficiency of penetration depth in sands is significant.

In order to evaluate the potential for improvement of the soil anchor-projectile, a modified projectile was conceived incorporating a more open configuration and a means to eliminate side-wall friction. Such a design should penetrate far enough to provide adequate holding capacity in all but the densest sands. Estimates of the penetration depth of such a modified projectile, having the same mass and set area (frontal area during pullout) as the existing projectile, are given in Table A-2 along with the previously cited depths for the existing projectiles. A comparison of values for the modified and existing projectiles indicates a substantial potential for improvement.

Energies furnished by the present launch vehicle are sufficient to provide adequate penetrations in some seafloor soils. Though the present sand projectile might perform satisfactorily in denser sands if sufficient penetration could be achieved, increasing the launch vehicle capacity to gain penetration depth appears impractical. Instead development of improved projectile designs needs to be undertaken to make optimum use of available embedment energy over a wide range of seafloor conditions.

Table A-1. Projected Areas of the SUPSALV Sand Anchor-Projectile at Various Stages of Penetration and Conditions of Soil Flow

Instantaneous Depth of Embedment	Condition of Central Cavity	Areas During Penetration ($in.^2$)		
		Flare Frontal	Total Frontal	Total Side
Partially Embedded	Free flowing	-	92	254d*
Fully Embedded	Free flowing	214	334	14,425
Partially Embedded	Plugged	-	638	90d
Fully Embedded	Plugged	214	852	4950

* d = depth of embedment (in)

Table A-2. Estimates of Penetration Depth for Existing and Modified Sand Anchor-Projectiles

Soil	Clay		Sand	
Angle of Internal Friction, ϕ (degrees)	-	-	30	40
Shear Strength, s (psi)**	0.7	2.8	14	70
Ultimate Penetration Depth of Existing Projectile (ft)	41.8	21.8	7.5	3.6
Ultimate Penetration Depth of Modified Projectile (ft)	72.8	49.5	22.5	9.5

** $s = \sigma' \tan \phi$ for sand

where σ' = critical confining pressure or hydrostatic pressure (Figure A-1)

Note: Weight of projectile = 2500 lb   Initial velocity = 200 ft/sec

Appendix B

ANCHOR HOLDING CAPACITY

by R. J. Taylor

The static pullout resistance of an embedded anchor-projectile may be calculated in various ways depending upon the soil type and anchor configuration.

Cohesionless Soil

One method for sands is based upon Vesic's (1969) analysis of the problem of the expansion of a spherical cavity close to the surface of a semi-infinite plastic solid. Vesic's theoretical analysis was chosen because it showed good agreement with results of model tests on loose to medium dense sand which would be typical of ocean depositions. Vesic's theoretical solution gives the ultimate radial pressure needed to break out a spherical cavity below the surface of a solid. The relationship is as follows:

$$q_o = c\bar{N}_c + \gamma_b D\bar{N}_q \qquad \text{(B-1)}$$

where q_o = radial pressure

c = soil cohesion

$\bar{N}_c = \bar{F}_c$

$\bar{N}_q = F_q + 1/2\ D/B$

$\bar{F}_c, \bar{F}_q$ = cavity breakout factors

γ_b = buoyant unit weight of the soil

D = embedment depth

B = circular plate diameter

The first term $c\bar{N}_c$ would be zero for a cohesionless material; c = o. Based on Equation B-1, the anchor holding capacity, F_T for a cohesionless soil can be calculated as follows:

$$F_T = \gamma_b D \bar{N}q A_F \tag{B-2}$$

where A_F is the anchor fluke area in plan.

The salvage sand anchor-projectile has a shape that is very difficult to analyze. It cannot be solely represented by either a rectangular, or a circular shape. The present approach is to bound the problem by calculating holding capacity of an anchor based on an equivalent circular area and based upon a continuous strip with comparable width and overall area. The difficulty with this technique lies in arriving at a realistic assumption of the embedment depth at which a particular anchor shape starts behaving as a "deep" anchor.

For each soil, there is a characteristic relative depth D/B (D/B = ratio of depth of embedment to fluke diameter) beyond which anchor plates start behaving as "deep" anchors and beyond which breakout factors reach constant final values (Vesic, 1969). Experimental data concerning "deep" anchors behavior are available for uniform circular and square anchor plates; however, nothing is available for rectangular sections.

Preliminary results of studies being conducted at the University of Massachusetts under a contract with NCEL to determine the breakout resistance of circular anchors embedded in saturated sands, indicate that this relative depth, D/B, varies for medium dense sand from 4 to 6. This agrees with the results of Baker and Kondner (1966) for dry sand of medium density. Being moderately conservative, all sands are assumed to be of medium density prior to anchor breakout. The sand in the areas where the explosive anchor was evaluated were of medium density (refer to Table 1 in text). Values of $\bar{N}_q$ used in Equation B-1 were assumed constant for the circular shape. In addition, for calculations it was assumed that the limiting depth, D/B, for the rectangular shape is D/B = 7. This appeared reasonable after comparing the soil stresses imposed by each shape of anchor. A brief model study to define the behavior of rectangular shapes during pullout is being initiated as part of another program.

Holding capacity in sand was calculated by first taking Vesic's results and plotting breakout factor, $\bar{N}_q$ versus relative depth, D/B, Figure B-1, and extrapolating to D/B = 7 for the rectangular shape. Second, $\bar{N}_q$ was plotted versus depth D, in Figure B-2, for the actual width of the sand fluke, B = 2 feet, and for the diameter of a circle with an equivalent area of the sand fluke, B = 6 feet. It appears that for this particular sand fluke, use of both assumptions will yield very nearly the same holding capacities to a depth of 14 feet, since $\bar{N}_q$ is directly related to holding capacity. Figure B-3 presents the relationship between static holding capacity, and depth for an ideal sand with the angle of internal friction, ϕ, varying from ϕ = 30 to 40°.

Cohesive Soil

An anchor plate in soft clay changes from a shallow to a "deep" anchor at a D/B of from 2 to 3 (Ali, 1968). A relative depth, D/B, of 3 was used for the rectangular plan flukes. At values of D/B >3, holding capacity was calculated according to Equation B-1, where $\bar{N}_q = 1$ for a cohesive ($\phi = o$) soil. The resulting equation is as follows:

$$F_T = cN_c A_F + \gamma_b D A_F \qquad \text{(B-3)}$$

where c = undrained shear strength

N_d = breakout factor

A_F = fluke area in plan

γ_b = buoyant unit weight

D = depth of embedment

Previous researchers, Mackenzie (1955) and Hanson (1953), have shown that "deep" anchor blocks in clay exhibit breakout factors, N_c, of 11 to 12 which roughly correspond to bearing capacity factors for deep foundations, Skempton (1959). Hanson's results are of particular interest because he showed that N_c increases by up to 25 percent when going from a smooth to a rough plate. The breakout factor, N_c, used in the calculations was $N_c = 11$. Figure B-4 presents anchor holding capacity versus depth for the sand anchor-projectile for a ratio of undrained shear strength to vertical effective stress, $c/\bar{p} = 0.5$. Seafloor soils are normally consolidated and can be classified by a constant $c/\bar{p}$ ratio for the depths of interest (6-30 feet). The results were plotted to separate the cohesive (F_c) and the overburden (F_y) components of the total holding capacity (F_T) to permit calculation of holding capacity for clays of various $c/\bar{p}$ ratios. Only $c/\bar{p} = 5$ was used to calculate the results shown in Figure B-4.

Summary

The preceding paragraphs illustrate techniques for developing the relationships between long-term static anchor holding capacity ', ' depth for two ideal soil types. These are a clean sand, c = o, .. a normally consolidated clay. The plotted curves are used after first determining anchor penetration depth and then estimating, from previous results, keying distance to determine the correct embedment depth from which to determine holding capacity.

It should be emphasized that holding capacities derived from these plotted curves are long-term static and do not account for such things as effects of creep and repetitive loading. A thorough understanding of the behavior of soils under various types of loading is necessary input into the holding capacity equations. These loading parameters are presently under investigation at NCEL and at the University of Massachusetts (NCEL Contract).

The holding capacity-depth relationships have not yet been wholly verified by full-scale tests; however, they are believed to be somewhat conservative due to the assumptions used in their development. In addition, adequate use of these or any other logically developed relationships between holding capacity and depth is entirely dependnet upon the ability to determine in-situ engineering properties of soils.

A prime consideration in further development of the SUPSALV anchor is to decrease the keying distance for the anchor flukes. Presently, the sand fluke requires a distance at least equal to 2 times its length to key. Figure B-3 indicates that a depth of 12 feet is required to achieve sufficient holding capacities in sand. However, this would require an initial penetration of 18 to 20 feet which is presently not likely to be achieved in a medium dense sand with the existing sand fluke. Research is on-going at NCEL to optimize the anchor-fluke projectile.

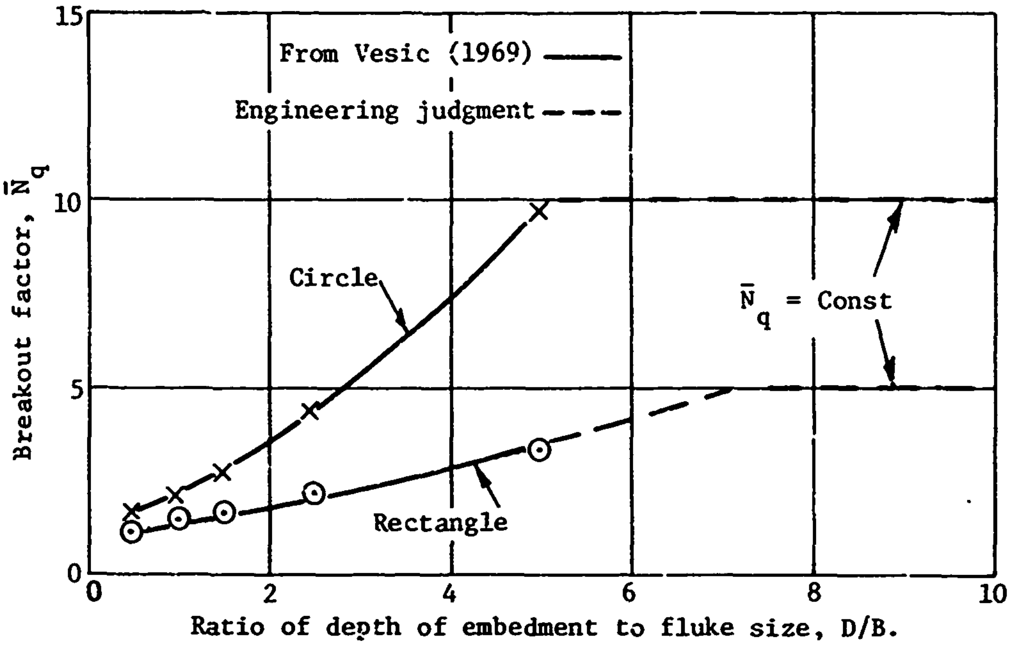

Figure B-1. Relationships between the breakout factor, $\bar{N}_q$, and the relative depth, D/B, at $\phi = 30^o$ for the SUPSALV sand anchor.

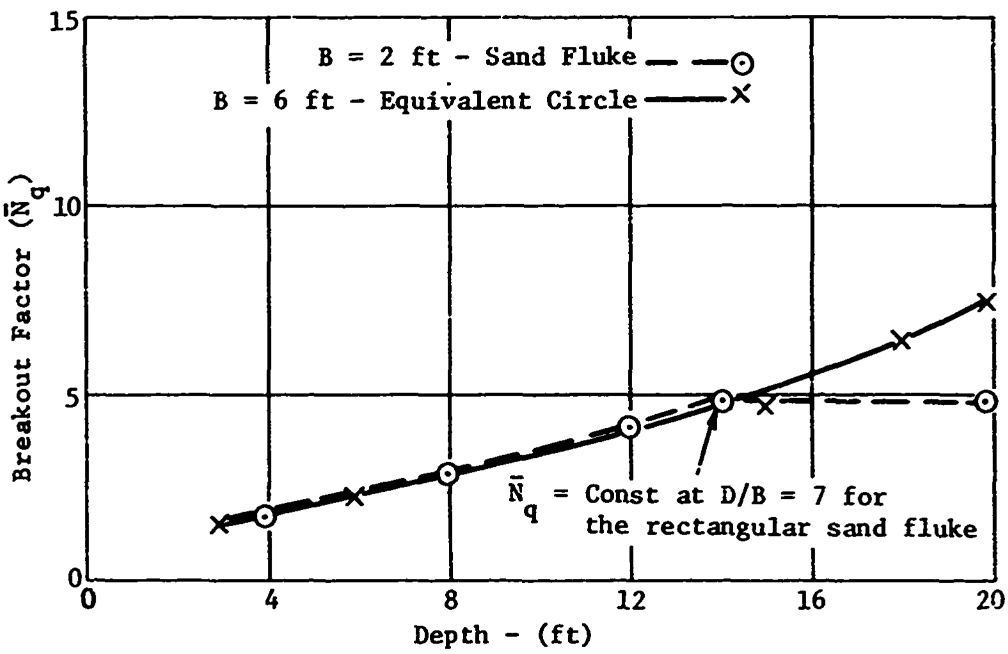

Figure B-2. Relationship between Breakout Factor and Depth for a clean sand with $\phi = 30^o$.

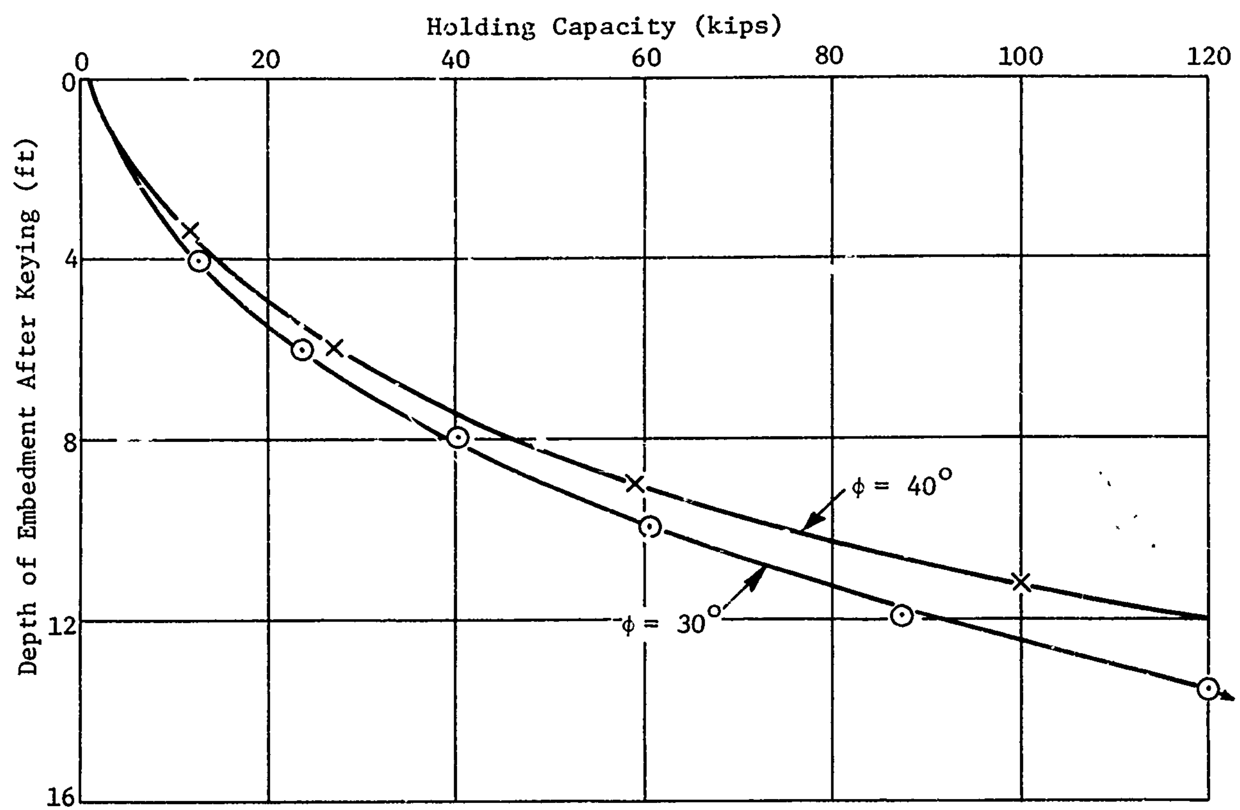

Figure B-3. Holding capacity versus depth of embedment (set) for an ideal sand, $c = 0$, $\gamma_b = 65$ pcf, for the SUPSALV sand projectile.

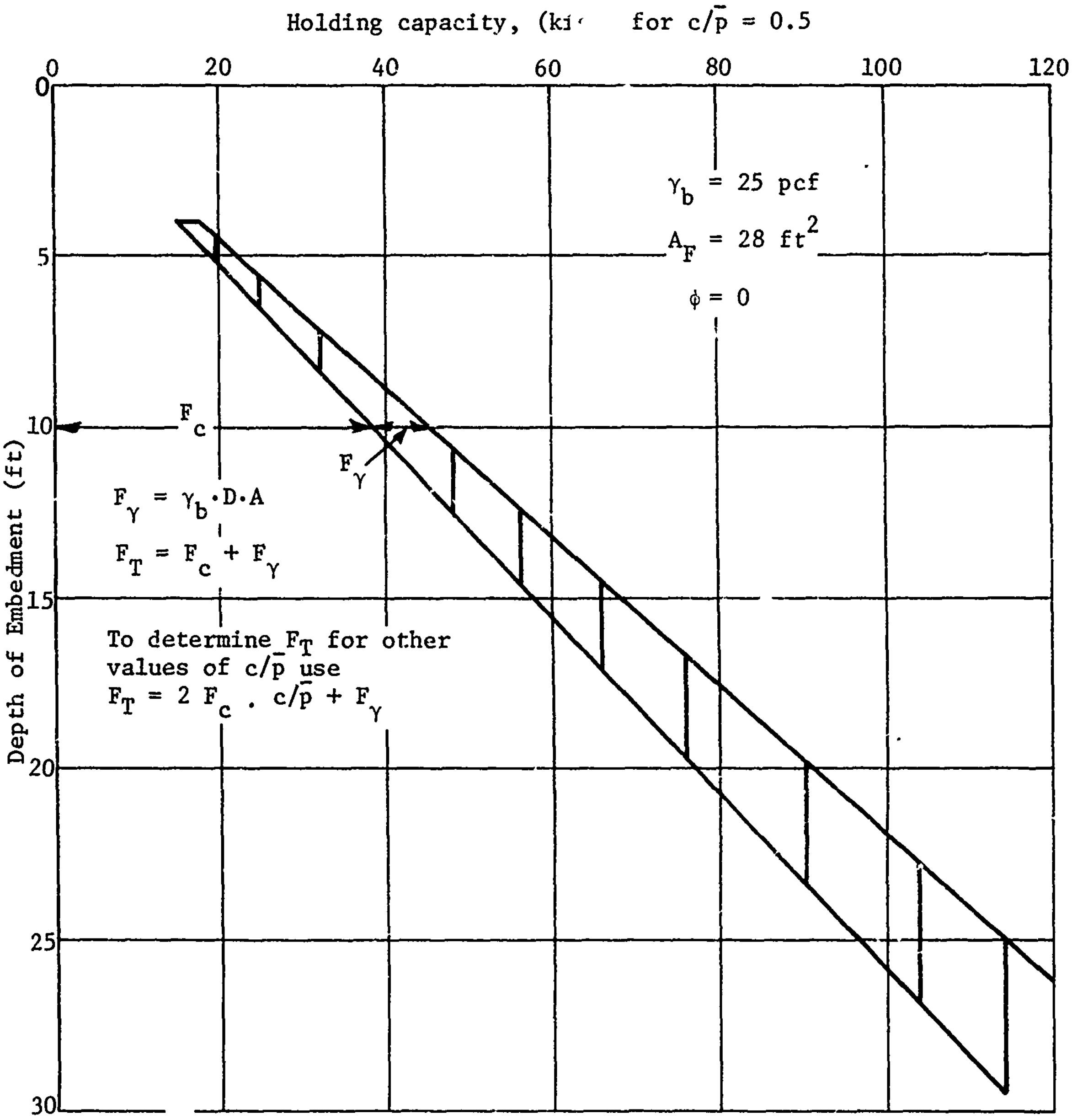

Figure B-4. Holding capacity versus depth of embedment (set) for an ideal clay for the SUPSALV sand anchor projectile.

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AD-735 108

ADDENDUM TO

Technical Note N-1186

EXPLOSIVE ANCHOR FOR SALVAGE OPERATIONS—PROGRESS AND STATUS

By

J. E. Smith

January 1972

NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California 93043

TABLE I. SEAFLOOR INFORMATION

Location	Description	Physical Data
Port Hueneme, California	Sandy Silt	Median Diameter of Grains = 0.4 mm
San Francisco, California	Plastic Silty Clay	Vane shear strength varies from 60 psf at surface to 150 psf at 7 feet
Anacapa Island, California	Basalt	Schmidt "N" Hardness 32 1" cube strength (unconfined) 16,400 psi Unit Weight 163 pcf
Key West, Florida	Fringe Reef Coral	Surface Texture-Moderately rough to rough Compressive strength (est.) 1500 to 2500 psi
Oahu Island, Hawaii	Fringe Reef Coral	Surface Texture-Smooth, scattered pockets of coral sand Compressive strength 1500 to 2500 psi
Cobb Seamount	Basalt	Surface Texture-Rough Compressive strength 20,000 psi

Table II. Test Program Summary

CONTRACTORS TESTING

Test No.	Test Date	Location	Work Platform	Seafloor	Water Depth (ft)	Anchor Type Used	Propellant Type	Propellant Load	Penetration (ft)	Holding Capacity (Kips)	Remarks
1	23 Jan 1968	Fort Erwin Calif.	NA	NA	NA	NA	M-6 Smokeless	7 lb .3 lb	NA	NA	Internal pressure 9430 psi. Muzzle Velocity 161 fps. A weight simulating an anchor-projectile was fired into the air from inverted gun barrel to measure internal pressures & muzzle vel.
2	24 Jan 1968	Fort Erwin Calif.	NA	NA	NA	NA	M-6 Smokeless	11 lb .3 lb	NA	NA	Internal pressure 13,500 Muzzel velocity 350 fps
3	25 Jan 1968	Fort Erwin Calif.	NA	NA	NA	NA	M-6 Smokeless	14 lb .3 lb	NA	NA	No pressure data Muzzle
4	7 Feb 1968	NCEL Port Hueneme	NCEL Warping Tug	Medium sand	45	sand	M-6 Smokeless	7 lb .3 lb	6		Flukes failed to open. All hardware recovered. Flukes were not free to rotate because of tight hinge points. Hinge and joints reworked.
5	13 Feb 1968	NCEL Port Hueneme	NCEL Warping Tug	Medium sand	40	sand	M-6 Smokeless	9 lb .3 lb	10	65	One fluke failed to open. All hardware recovered. Flukes hinge joints reworked. Reaction vessel damaged and returned to Fullerton.
6	27 Feb 1968	NCEL shallow water test area	YFU	Medium sand	35	sand	M-6 Smokeless	11 lb .3 lb	18	no data	All hardware recovered. Flukes reworked by flaring tips 15°.
7	1 Mar 1968	NCEL shallow water test area	YFU	Medium sand	35	sand	M-6 Smokeless	12 lb .3 lb	5		Piston lost during recovery operation.
8	7 Mar 1968	NCEL shallow water test area	ARS (USNS Gear)	Medium sand	40	sand	M-6 High Velocity	12 lb .4 lb	no data	120	One down haul cable and one pendant cable broke in excess of 130,000 lbs when ship surged in heavy ground swells. Anchor-projectile lost but piston was recovered.
9	16 Mar 1968	San Francisco Bay	ARS (USNS Gear)	Mud (clay)	35	mud	M-2 High Vel.	4 lb .4 lb	54 estimated	78	All hardware recovered.
10	19 Mar 1968	San Francisco Bay	ARS (USNS Gear)	Mud (clay)	35	mud	M-2 High Vel.	4 lb .4 lb	12	no data	All hardware recovered.
11	21 Mar 1968	San Francisco Bay	ARS (USNS Gear)	Mud (clay)	35	mud	M-2 High Vel.	4 lb .4 lb	34	92	Socket on projectile end of down haul cable failed. Excessive surge load broke second down haul cable in excess of 90,000 lb. Anchor projectile not recovered.
12	28 May 1968	Key West J Marker	YFNT	Coral	52	coral[1]	WC-870	4 lb	8	68	Coral test anchor utilized complete ordnance system including safe and arm, explosive bolts, interline, etc.
13	8 July 1968	Key West	ASR (USS Penquin)	Coral	50	coral[2]	WC-870	4 lb	7	120	Anchor extracted after holding 120,000 lbs for 20 minutes.
14	9 July 1968	Key West Vestal Shoals	ASR (USS Penquin)	Coral	50	coral[2]	WC-870	5 lb	11	128-136 (surge)	Coral projectile held 128,000 lb for 20 minutes 30,000 to 60,000 lb vertical pull for 10 hours required to extract the anchor.

Continued

Table II. Test Program Summary (continued)

	Test No.	Test Date	Location	Work Platform	Seafloor	Water Depth (ft)	Anchor Type Used	Propellant Type	Propellant Load	Penetration (ft)	Holding Capacity (Kips)	Remarks
NCEL TESTING	15	12 Dec 1968	Anacapa Island	ATF (USS SIOUX)	Rock (basalt)	55	coral[2]	M-2 WC870	5 lb 2 lb	3'-7"	45-50	Anchor-projectile recovered undamaged.
	16	13 Dec 1968	Anacapa Island	ATF (USS SIOUX)	Rock (basalt)	52	coral[2]	M-2 WC870	8 lb 1 lb	4'-2"	64	Anchor-projectile recovered undamaged.
	17	15 Dec 1969	Anacapa Island	ATF (USS SIOUX)	Rock (basalt)	56	coral[3]	M-2 WC870	10 lb 1 lb	5'-1"	168 vertical pull	Three separate pull attempts at different dates made on this anchor. Anchor-projectile was trimmed to arrow shape.
	18	22 Feb 1969	San Francisco Bay Naval Shipyard	ATF (USS SIOUX)	Mud (clay)	35	sand	M-6 WC870	8 1	NA		Three attempts were made to fire the anchor using the S&A device. Each time the S&A malfunctioned. Finally, tests 19, 20, and 21 were conducted using a direct electric firing cable.
	19	24 Feb 1969	San Francisco Shipyard	ATF (USS SIOUX)	Mud (clay)	35	sand	M-6 WC870	8 1	35 (est.)	63	
	20	25 Feb 1969	San Francisco Bay Naval Shipyard	ATF (USS SIOUX)	Mud (clay)	35	mud	M-6 WC870	6 1	35 (est.)	58	Anchor-projectile flukes only partially opened and were damaged.
	21	26 Feb 1969	San Francisco Bay Naval Shipyard	ATF (USS SIOUX)	Mud (clay)	35	sand	M-6 WC870	11 1	45 (est.)	92	One of th[illegible] flukes did not open apparently because p[illegible] bracing arm were jammed.
	22	2 Apr 1969	So. Coast Oahu Island, Hawaii	ARS (USS GRAPPLE)	coral	50	coral[4]	M-2 WC870	8 lb 1 lb	9' (est.)	65	Failed to fire first try due to S&A malfunction Anchor was then fired by electrical cable.
	23	3 Apr 1969	So. Coast Oahu Island, Hawaii	ARS (USS GRAPPLE)	coral	60	coral[4]	M-2 WC870	13 lb 1 lb	11'	75+	These two anchor-projectiles were fired by electric cable by-passing the S&A. After placement they were used to provide a reaction for the test of the anchor in Test No. 25. All three anchors held at the loads indicated, and the anchors are still in place
	24	4 Apr 1969	So. Coast Oahu Island, Hawaii	ARS (USS GRAPPLE)	coral	48	coral[4]	M-2 WC870	13 lb 1 lb	11'-5"	75+	
	25	4 Apr 1969	So. Coast Oahu Island, Hawaii	ARS (USS GRAPPLE)	coral	48	coral[4]	M-2 WC870	13 lb 1 lb	11'-5"	150+	This anchor-projectile also was fired by electric cable. It held in excess of 150k, the maximum the ship was able to apply. During placement the struts of the launch vehicle separated. Later it was determined they had not been heat treated properly.

Continued

Table IX. Test Program Summary (continued)

Test No.	Test Date	Location	Work Platform	Seafloor	Water Depth (ft)	Anchor Type Used	Propellant Type	Propellant Load	Penetration (ft)	Holding Capacity (kips)	Remarks
26	11 Aug 1969	Mouth of harbor Port Hue.	NCEL Warping Tug	Sand	50	coral	M-2 WC-870	9 lb 1 lb	NA	NA	Internal pressure 13,050 psi - measured Internal pressure 12,900 psi - computed Muzzle velocity 242 fps - measured Muzzle velocity 272 fps - computed
27	12 Aug 1969	Mouth of harbor Port Hue.	NCEL Warping Tug	Sand	50	coral	M-2 WC-870	14 lb 1 lb	NA	NA	Internal pressure 14,800 psi - measured Internal pressure 14,600 psi - computed Muzzle velocity 280 fps - measured Muzzle velocity 288 fps - computed The 14-lb charge did not completely detonate: only 9.8 lbs detonated.
28	23 Aug 1969	Cobb Sea Mount	USCG IVY	Rock (basalt)	120	coral	M-2 WC-870	13 lb 1 lb	no data	some	Acceptable penetration was attained, but the anchor projectile was damaged by impact with the basalt.
29	11 Feb 1970	Near mouth of harbor, Port Hue.	NA	NA	700	NA	NA	NA	NA	NA	Safe and Arm device potted with RTV in electronic chamber successfully fired at this depth indicating effectiveness of this method to seal against leakage.
30	17 Mar 1970	NCEL SEACON Test Area	NA	NA	600	NA	NA	NA	NA	NA	Operations test to determine if anchor could be lowered in depths to at least 500 feet was conducted. Anchor and beach gear leg were lowered successfully but accuracy of desired location was poor. Operation very sensitive to sea conditions.
31	30 June 1970	SEACON Test Site	NCEL Warping Tug	Silty Clay	600	Sand	M-6 WC-870	11 lb 1 lb	none	none	The launch vehicle was jerked strongly during lowering from warping tug. The touchdown firing mechanism malfunctioned and the anchor fired prematurely at a depth of 100 feet. All equipment except the piston was recovered.

[1] Original contractor coral anchor-projectile.

[2] Revised design enlarged and serrations included on outer of fins.

[3] Tip of revised design made more pointed to better penetrate rock.

[4] Swivel attachment point installed on revised design.